50th Annual Fuze Conference

"50 Years of Support Freedom"

9 - 11 May 2006

Norfolk, Virginia

Session I & II: *OPENING REMARKS AND KEYNOTE & GENERAL SESSION*
• **Keynote: Mr. Rene Kiebler**, Deputy Project Manager Combat Ammunition Systems, PEO Ammunition
• OSD Perspecctive, **Mr. Peter A. Morrison**, Staff Specialist OUSD/DDR&E(S&T) Weapons Technology
• PEO Ammo Perspective, **Mr. Rene Kiebler**, Deputy Project Manager Combat Ammunition Systems, PEO Ammunition
• US Army RDECOM ARDEC Perspective, **Dr. Joseph Lannon**, US Army RDECOM ARDEC
• Navy Overview, **Mr. Steve Mitchell**, Ordnance Project Area Director, NAVSEA
• Air Force S & T Strategy, **Mr. Timothy Tobik**, Air Force Research Laboratory, Eglin
• Air Force Acquisition Strategy, **Mr. J. Rick Holder**, Sr., Director Fuze Squadron USAF, Eglin
• Fuze IPT Perspective, **Mr. Lawrence Fan**, Fuze and Microsystem Project Manager, NSWC

Session IIIA: *OPEN SESSION*
• PGMM, New Application for an Existing Fuze, **Mr. Al DeSantis**, Picatinny Arsenal, NJ
• Proximity Sensor for the Guided Multiple Launch Rocket System (GMLRS), **Mr. Robert P. Hertlein**, L3 Communications - KDI Precision Products
• Portable Excalibur Fire Control System, **Mr Gregory Schneck**, US Army RDECOM ARDEC
• Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS), **Mr. Tom Walker**, US Army RDECOM ARDEC Adelphi Fuze Division
• The Evolution of the DSU-33 C/B Proximity Sensor, A Success in Customer-Contractor Partnership, **Mr. Michael J. Balk**, ATK Ordnance Systems
• A New Fuze for an Electromagnetic Gun, **Mr, Barry Schwartz**, US Army RDECOM ARDEC
• Introduction of the Multi Option Fuze Artillery (MOFA) DM84 on 120mm Rifled Mortar, **Mr. Jochen Wagner**, JUNGHANS Feinwerktechnik

Session IVA: *OPEN SESSION*
• Challenges Associated with Development of the Affordable Weapon System Fuzing System, **Mr. John Hubert**, L-3/KDI Precision Products, Inc.
• FMU-139C/B. Electronic Bomb Fuze Design Update, **Mr. David Liberatore,** ATK
• Shipboard Submunition Fuze Safety and Realiability Enhancements, **Mr. John Kunstmann**, Indian Head Division, NSWC
• Thermal Battery Development - Reduced Product Variability Through 6-Sigma, Automation and Material, **Mr. Paul F. Schisselbauer** and **Mr. John Bostwick**, ATK
• Performance Testing of Lead-Free Stab Detonators, **Mr. Neha Mehta**, US Army RDECOM ARDEC
• TNO Research on EFI's in Relation to Insensitive Munitions, **Mr. Wim Prinse**, TNO Defence, Security and Safety

Session VA: *OPEN SESSION*
• Hight-G Mortar Electronic S&A Development and Flight Test, **Mr. Cuong Nguyen**, US Army RDECOM ARDEC
• Safe Separation Study for MK 437 Mult-Option Fuze for Navy (MOFN), **Mr. Brian Will**, NSWC, Dalhgren
• Navy Proximity Fuze Simulation with Embedded Tactical Software, **Mr. John Langan**, NSWC WD
• Inadequacy of Traditional Test Methods for Detection of Non-Hermetic Energetic Components, **Mr. Karl Rink**, University of Idaho
• Weapons Reliability How Modern Warfare has Changed the Requirement, **CDR Tom Hole**, USN, US Navy PMA-201
• MAFIS a Proven Hard Target Fuze, **Mr. Laurie Turner**, Thales Missile Electronics
• Aurora a Proven Hard Target Fuze, **Mr. Richard Clutterbuck**, Thales Missile Electronics

50th Annual Fuze Conference

Thursday, May 11

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION
STRENGTH THROUGH INDUSTRY & TECHNOLOGY

- Session V-A (Chair: Leonard Friedman)
  - 1:00 Miniature ISD Design for GMLRS
  - 1:20 High-G Mortar Elec. S&A Develop. And Testing
  - 1:40 Safe Sep. Study for MK 437 Multi-Option Fuze
  - 2:00 Navy Proximity Fuze Simulation w/embedded…
  - 2:20 Inadequacy of Traditional Test Methods….
  - 2:40 Weapons Reliability-How Modern Warfare…
  - 3:00 BREAK
  - 3:20 MAFIS a Proven Hard Target Fuze
  - 3:40 Aurora a Proven Hard Target Fuze
  - 4:00 A Rapid Prototyping Process for Fuze Development
  - 4:20 Solid Foundations and White Hair: A Fuzing Per…
  - 4:40 Wrap-up / Conference Adjournment

Aurora Fuze for PGB PWIV

R C D'A Clutterbuck

NDIA Fuze Conference 11 May 2006

Missile Electronics

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Hard Target Fuzing Perspective

- Weapon Background and Capability
  - ➔ Paveway™ IV
- Fuze Background
  - ➔ MEHTF-PSFT
- Fuze Second Environment Sensing
- Programme Status

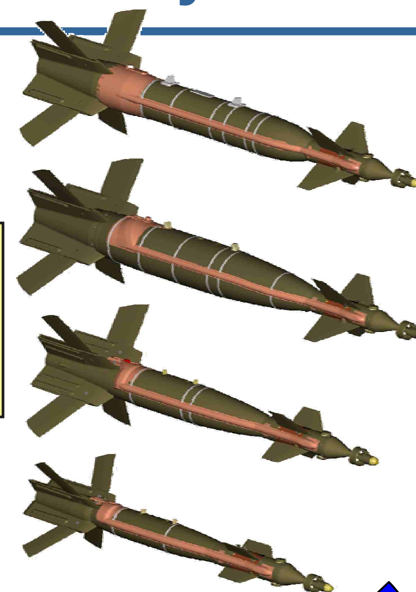
The Paveway™ IV Family Tree

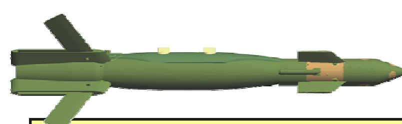
Raytheon
Systems Limited

Paveway™ II
- Laser Guided Bomb family

UK EPII UOR
- All-Weather
- Dual-Mode GPS & Laser Guided
- Combat Proven

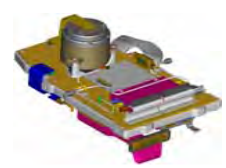
EP II Lot 3
- All-Weather Dual Mode
- GPS A/J SAASM
- Mk 80 series/BLU 109



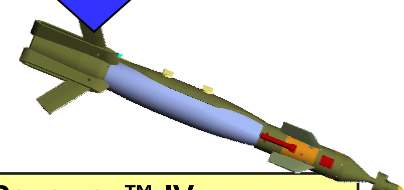


Paveway™ IV Baseline
- GPS A/J SAASM
- Air Burst
- Smart Fuze
- Mk 82 Improved Warhead with IM

PAVEWAY™ IV



Common Guidance Electronics
- Paveway Global Factory
- All manufactured by RSL in Glenrothes



Paveway™ IV
- All-Weather Dual Mode

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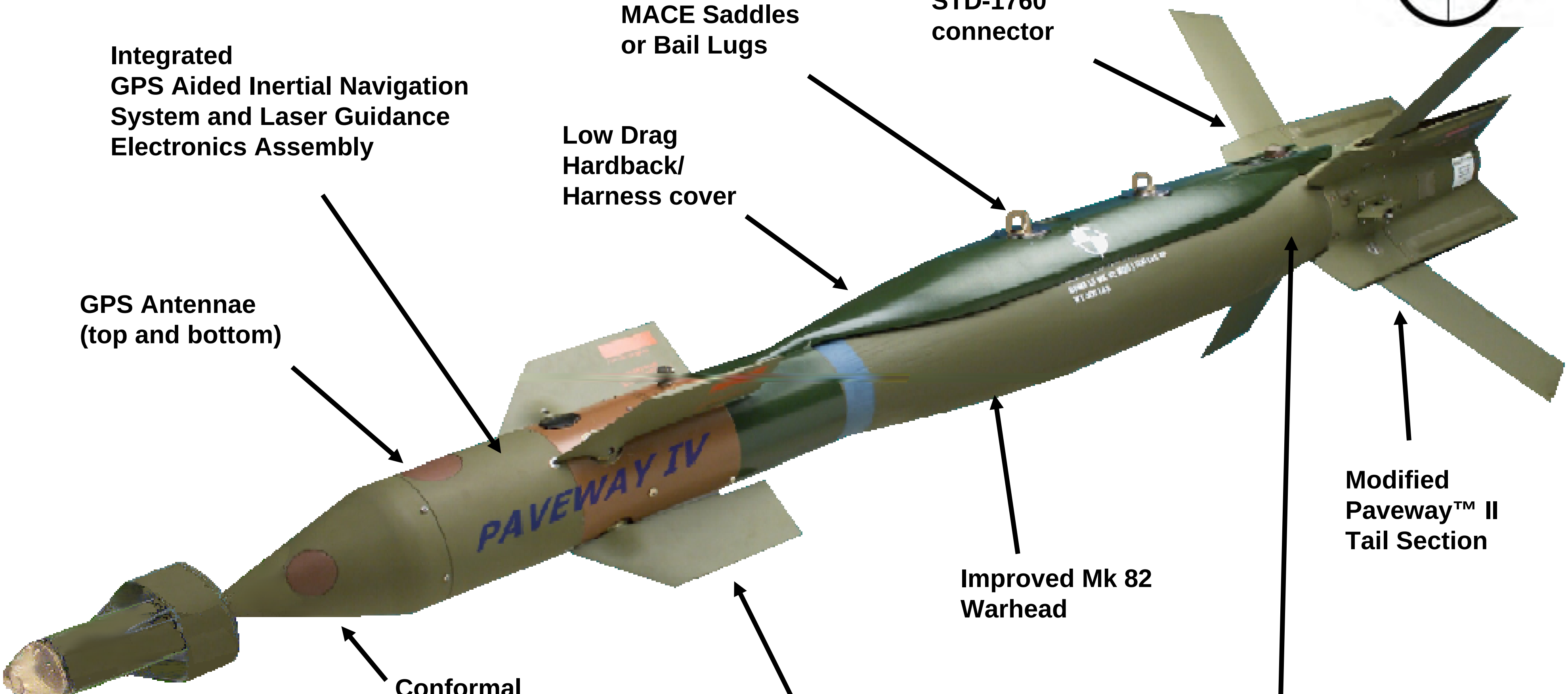
Paveway™ IV Components

Raytheon Systems Limited

PAVEWAY™ IV



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TME is a Fuzing Company

Building hardened fuzes since 1914

World's first In service Proximity Fuze (710 Electro Optical Pistol) ('42)

World's first hardened and electronic multifunction bomb fuze (MFBF) - 1981

- **27,500 MFBF built**
- **Successful FCT trial at Eglin - 1992**
- **Used by RAF, RSAF and USAF in Desert Storm**
- **Kosovo data indicates >99% reliability for MFBF in 400+ releases**

Pioneer in modern fuze hardened electronics

1918	-	**Shell Fuzing**
1940's	-	**Airborne Radar, Shell Fuzing, Proximity Fuzing (Rockets)**
		Bomb Fuze for "Bouncing Bomb" etc.
1950's	-	**Naval Proximity Shell Fuzing**
1960's	-	**No.907 RF Proximity Fuze for Bombs.**
1970's	-	**No.952 RF Proximity Fuze for Bombs.**
		Multi Role programmable Shell Fuze (MRF)
1980's	-	**SG357 Runway Cratering Weapon**
		MFBF (No.960) Multi-Function Bomb Fuze
1990's	-	**Intelligent Hard Target Fuzing Research**
		EPIFS
2000's	-	**Intelligent Hard Target Fuzing.**
		MAFIS, HTSF, MEHTF
		PGB/ABF
		BDI/BDA
		Fuzing in High Speed Impacts
		Paveway IV

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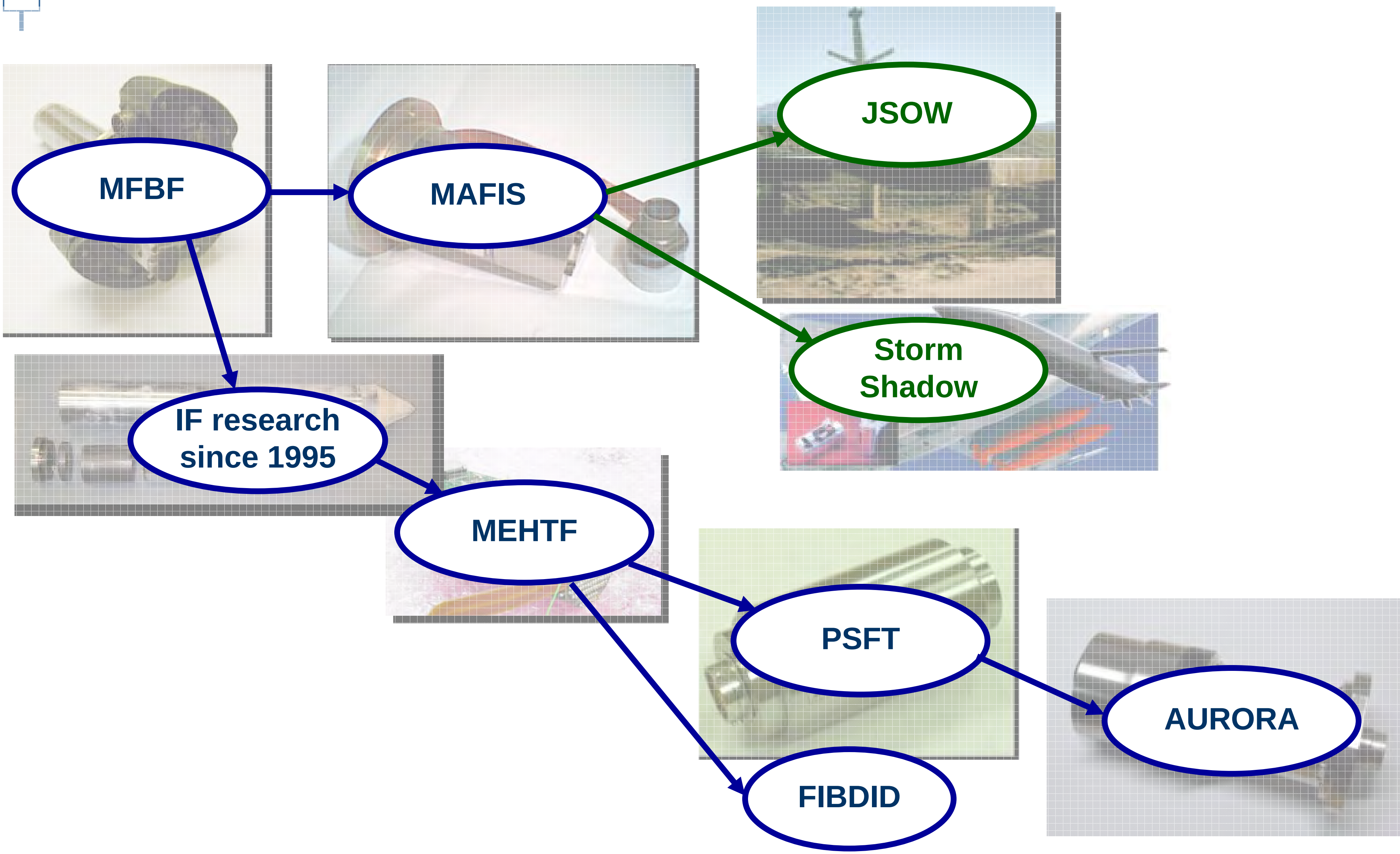
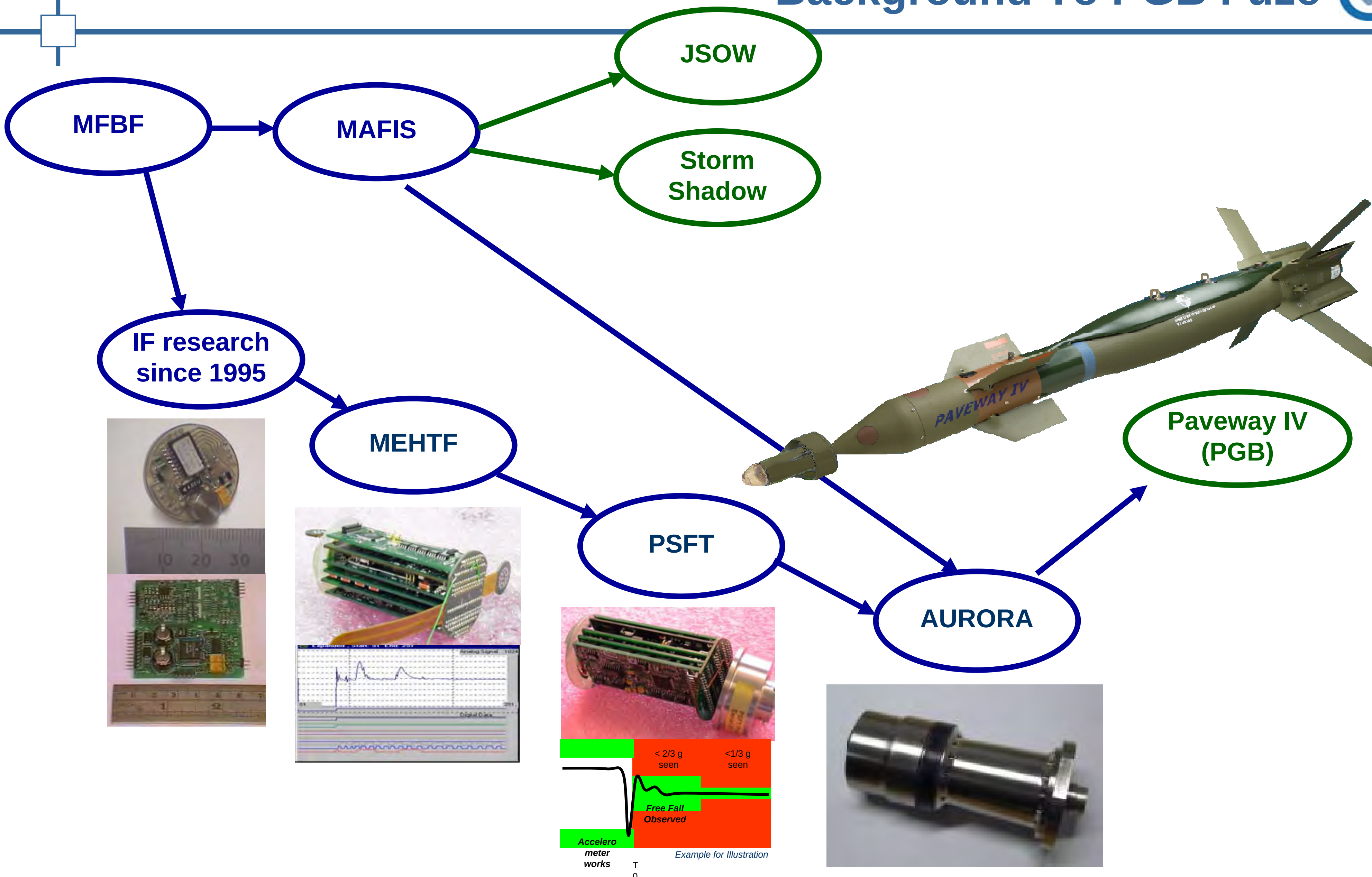
TME Bomb Fuzing Family Tree



Background To PGB Fuze



Summary of Requirements for Safety Sensors:

1: Sense the Intentional Release from the launch platform

2: Confirm Weapon has been released into the expected environment

(Operation of at least one of the independent safety features shall depend on sensing an environment after first motion in the launch cycle or on sensing a post launch environment.) STANAG 4187 6b3

Typical Sensors used in past

Air speed,

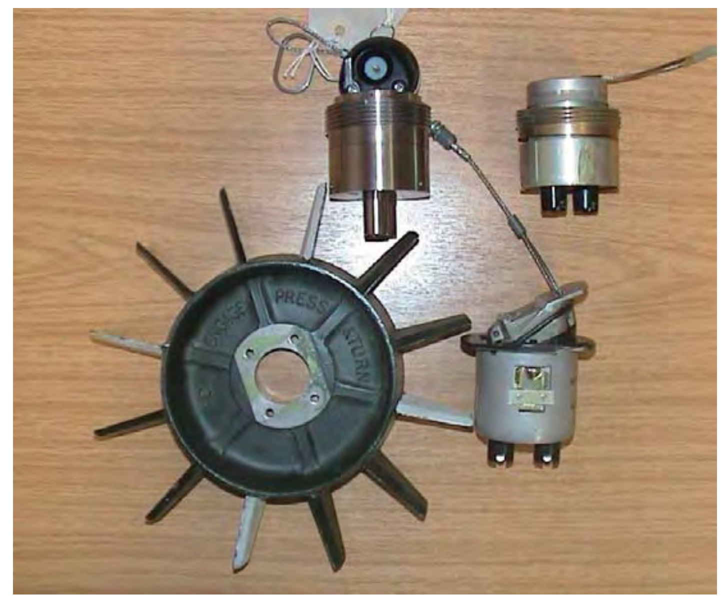
Can provide power sources

(Bigger Area :- More Power {& Drag!})

But: senses an environment that is not totally unique to “release”

(mainly is “lanyard pulled”)

Also issues with high altitude, thin air, Damage, drag etc.



Typical Sensors used in past

Air pressure:

- **Pitot (air speed)**
- **Motor operating**

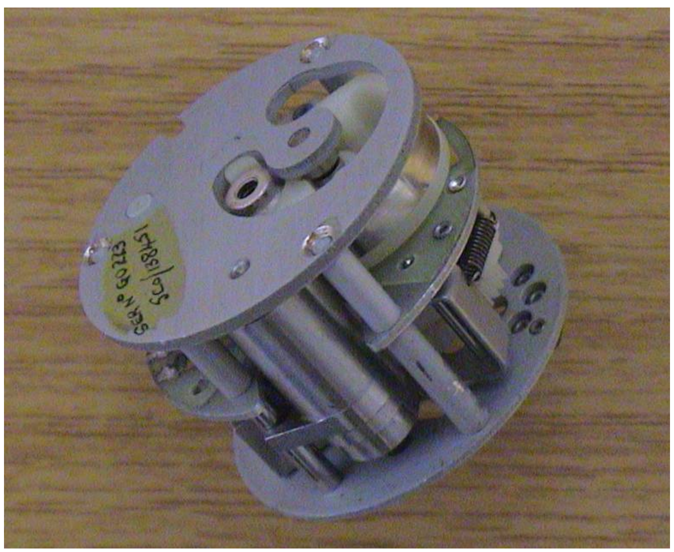
Fuze Second Environment Sensing

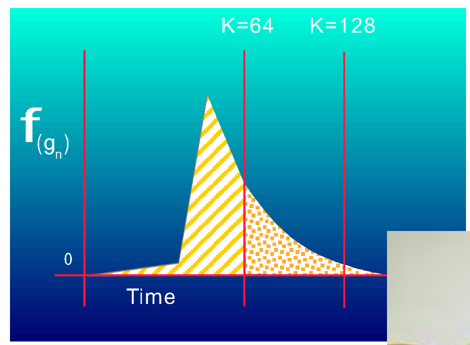
Typical Sensors used in past

Acceleration sensing:

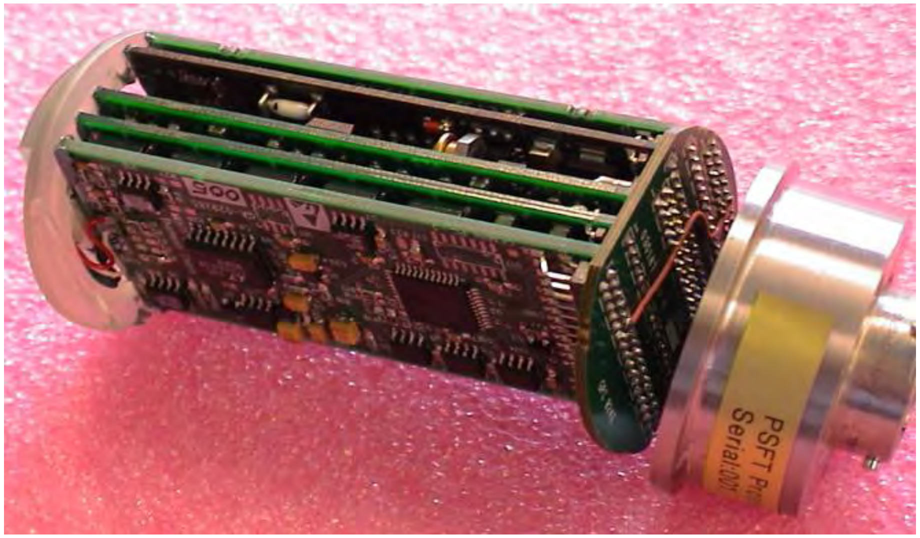
Parachute operation detection

(Both Mechanically and Electrically)





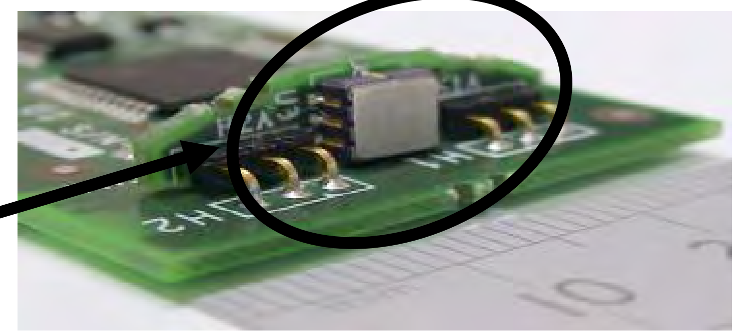
PSFT Phase II Research added Improvements on MEHTF

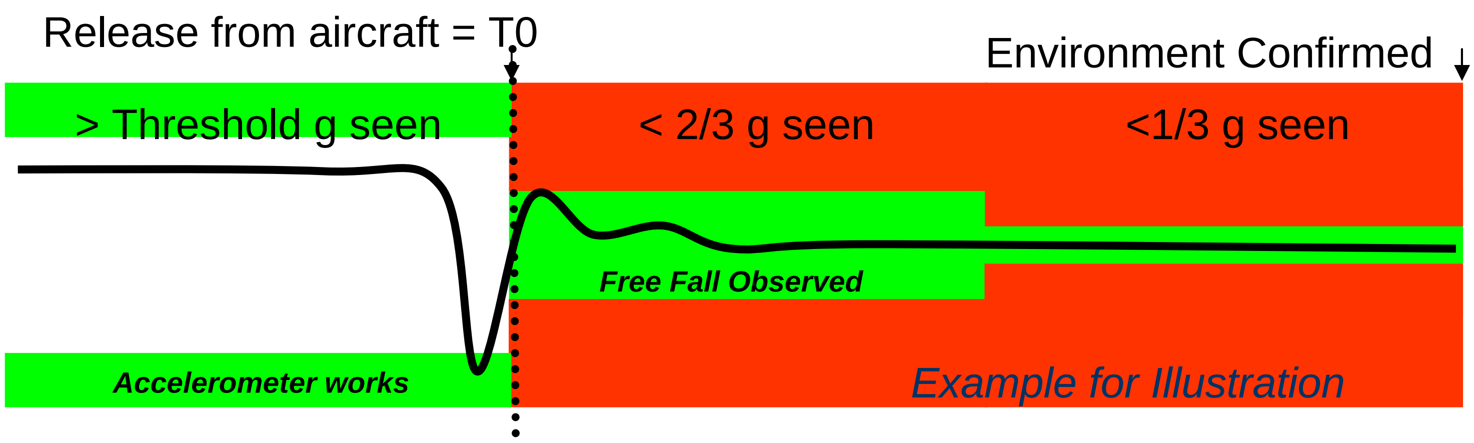


- **Improved Safety Architecture**
  - ➔ **Late Arm**
  - ➔ **Potential for different Arming sensor suites**
    - **Release Environment Observation**

PSFT Fuze Internal "Second" Environment Sensing

- PSFT introduced crossed axis MEMS Accelerometers and Processor to sense Post Release Environment





EXAMPLE : Internal Fuze Accelerometers monitor unique post launch zero g environment to confirm post launch environment.

: Accelerometer confirmed OK by sensing release & or carriage loads

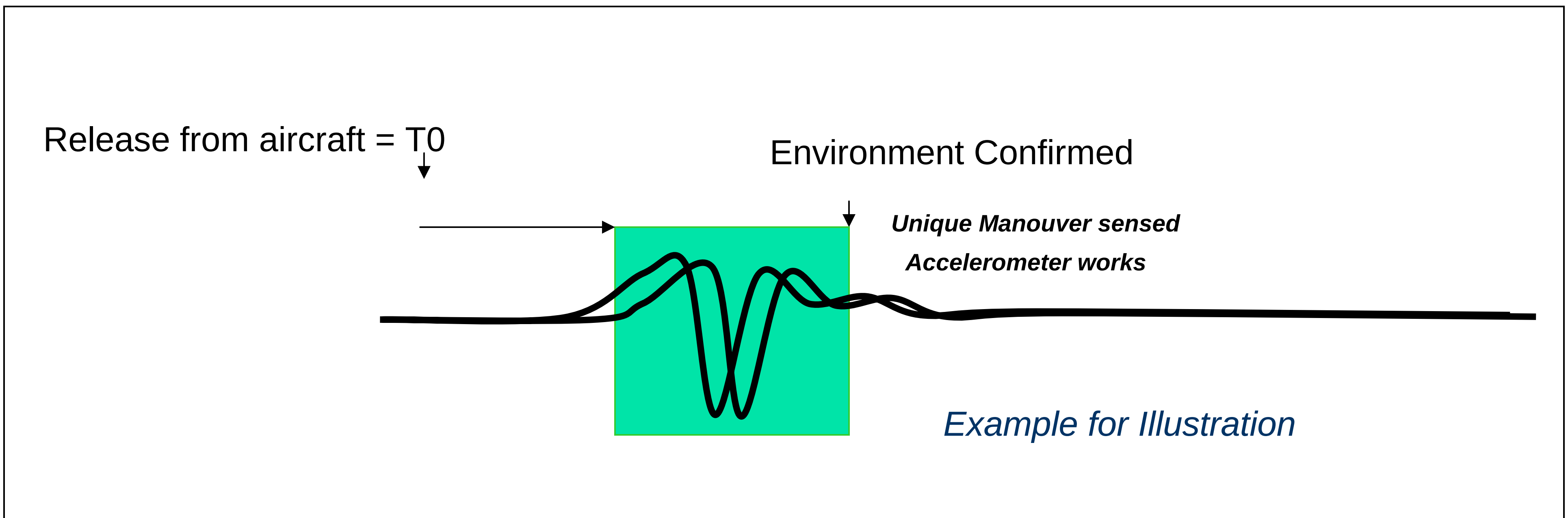
AURORA Fuze for PGB (Paveway IV)

Develop, qualify & manufacture, 2003 - 2006

Built on PSFT:

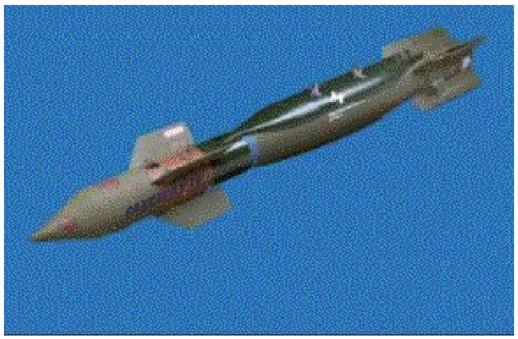
Decided to make system independent of release shocks:

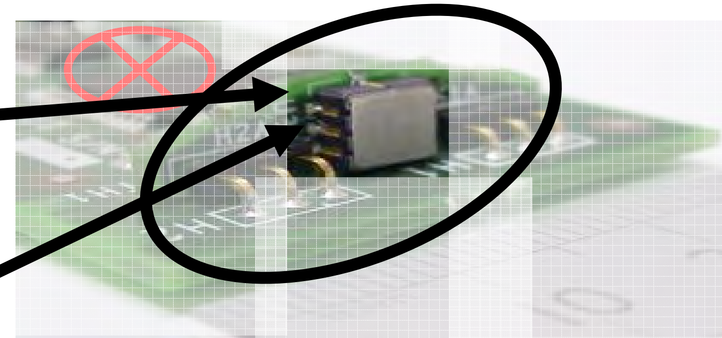
Initially: use a Timed Manoeuvre

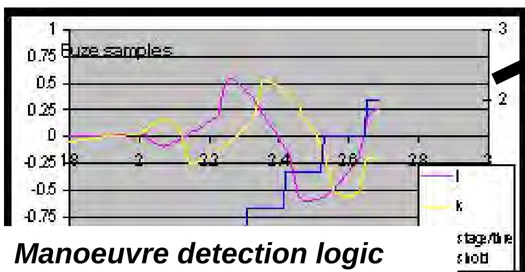


AURORA Fuze for PGB (Paveway IV)

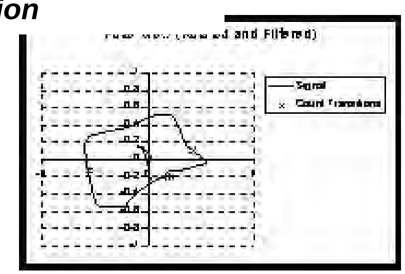
PGB PSFT Accelerometers and New Hardware to sense Timed, Co-operative Weapon Post Release Manoeuvre







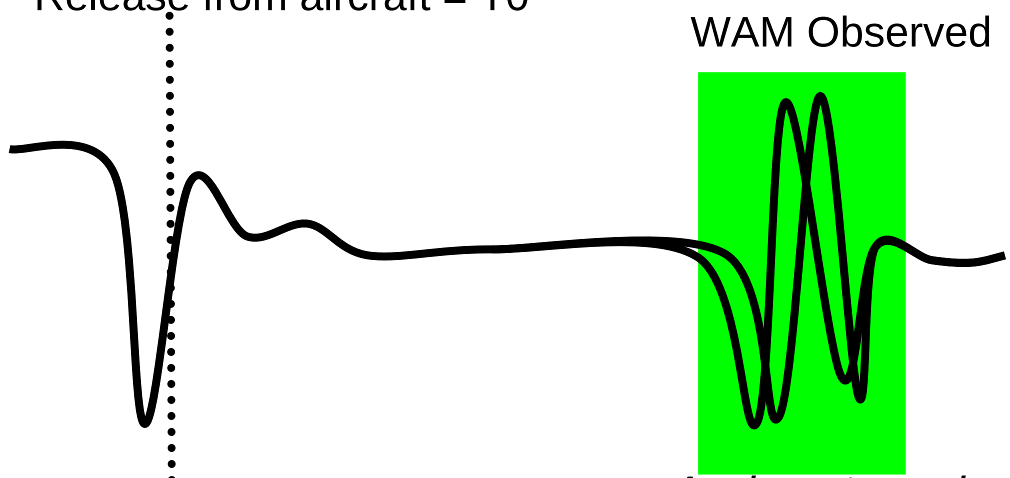
Manoeuvre detection logic simulation



Modelling undertaken of of 1000 simulated releases

Release from aircraft = T0

WAM Observed



Accelerometers work
WAM Timing and Phase Observed

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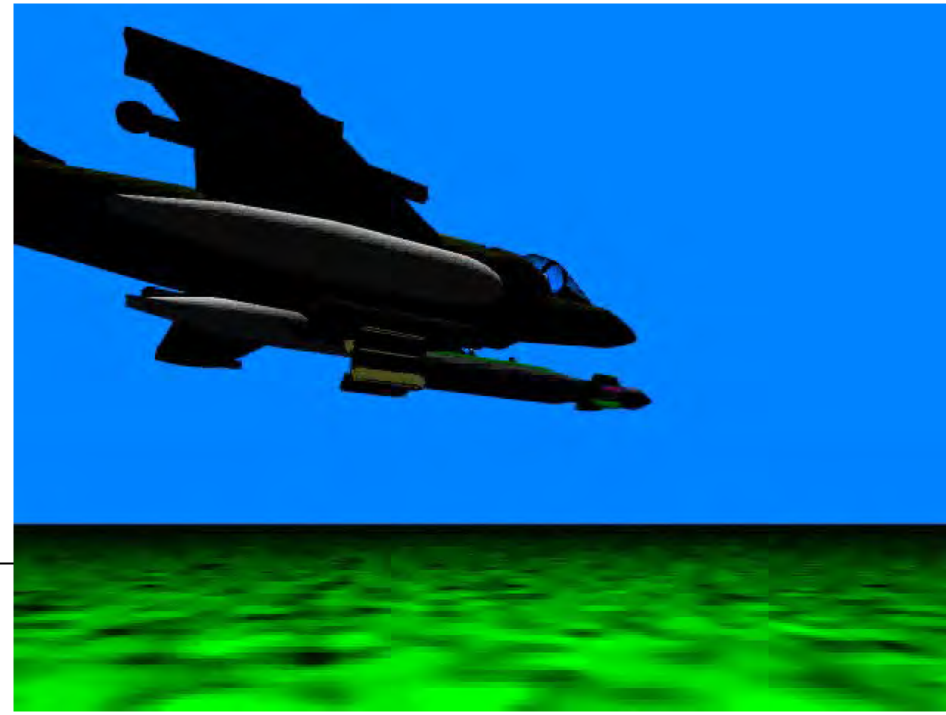
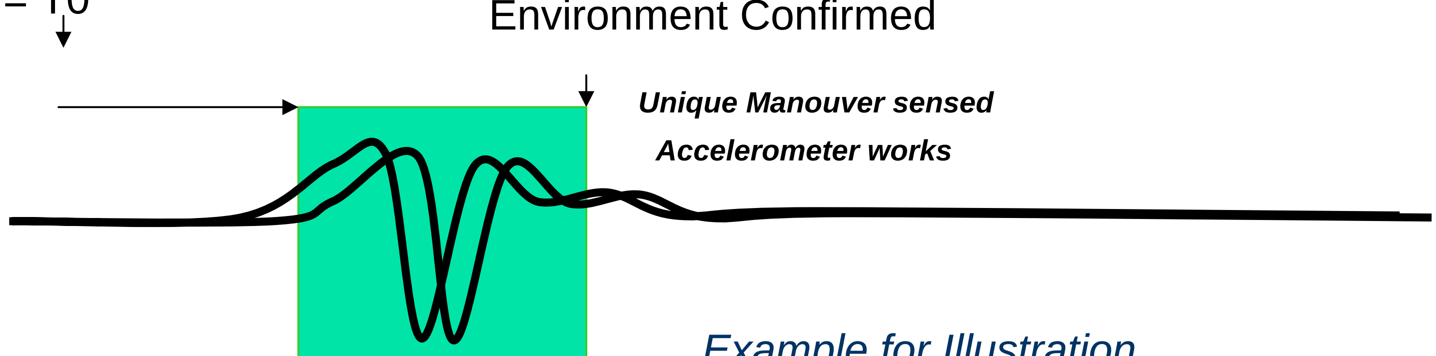
WAM Option

Initial Concept



Release from aircraft = T0

Environment Confirmed



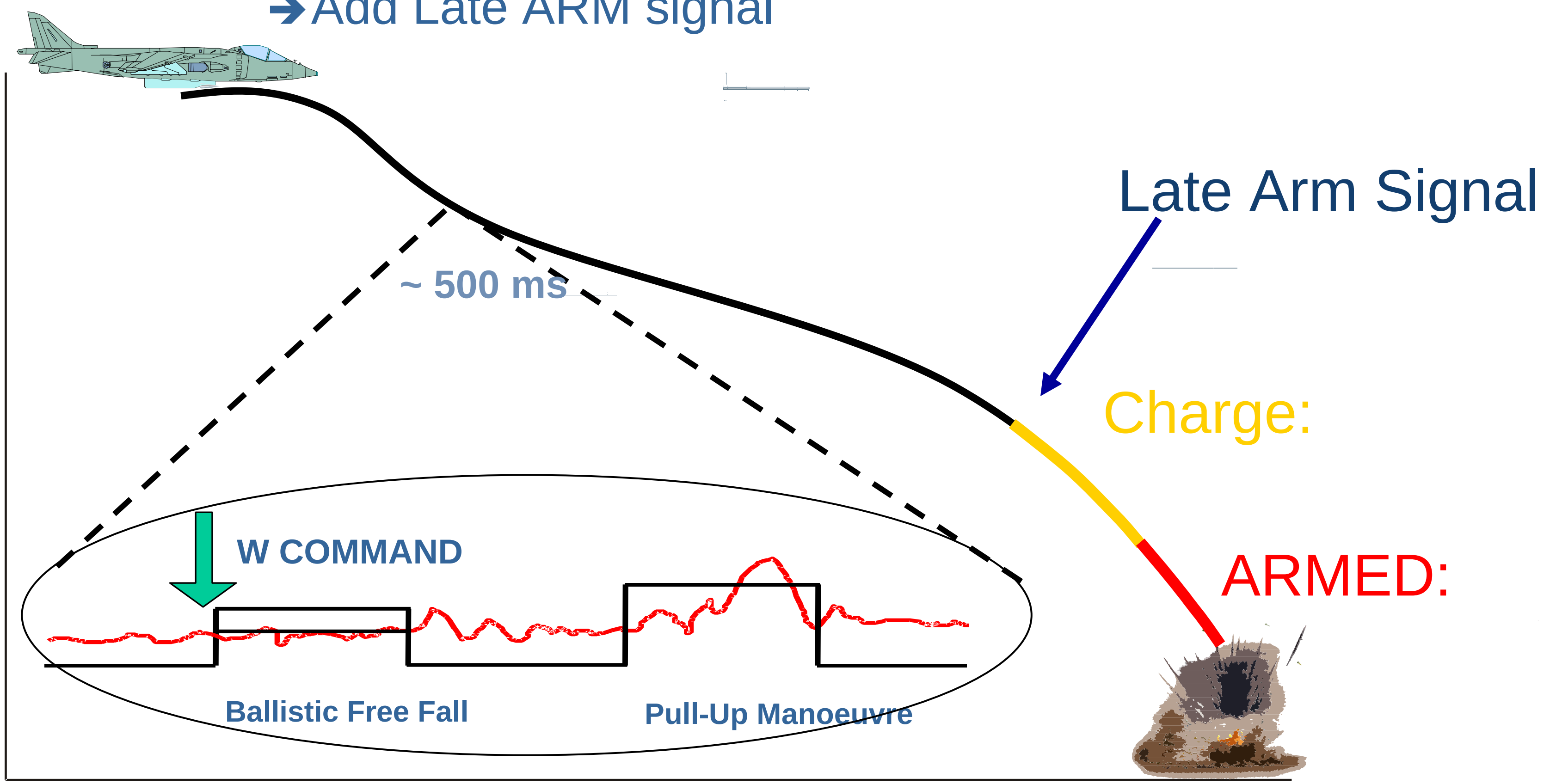
Unique Manouver sensed

Accelerometer works

Example for Illustration

Further Improved concept:

- ➔Allow weapon to determine when to make manoeuvre:
- ➔Simplify Manoeuvre into 2 Stages:
- ➔Add Late ARM signal



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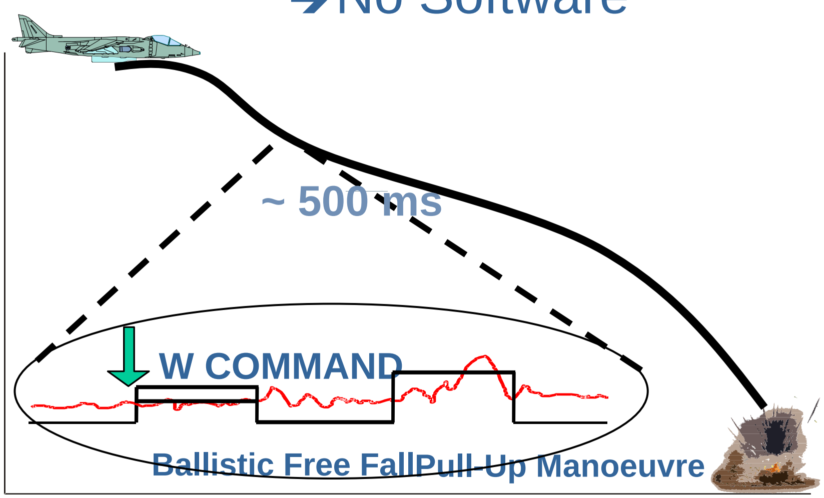
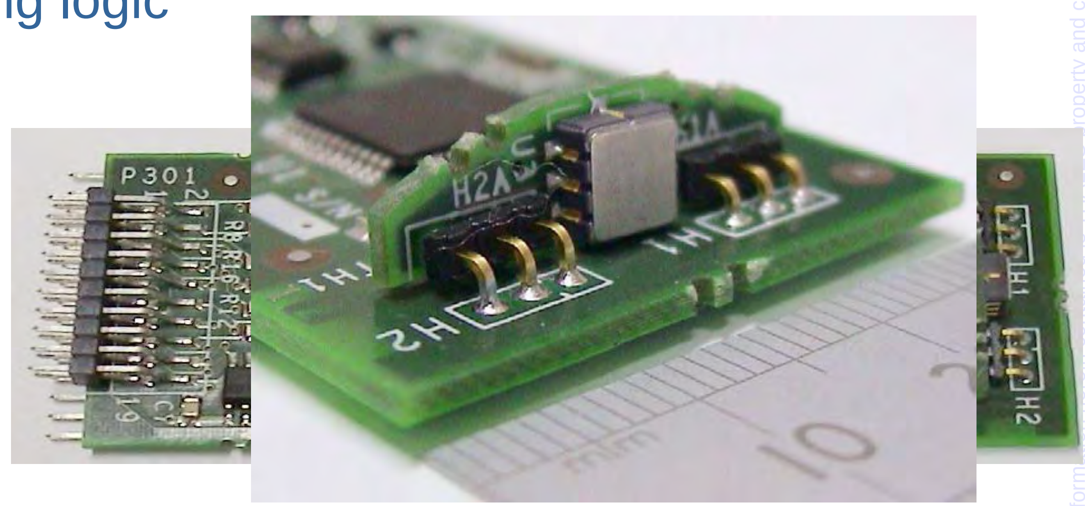
Advantages:

- Manoeuvre is at commanded time:
  - ➔Can be delayed to Lower Altitudes
  - ➔When convenient to Weapon
  - ➔Expands release envelope
- Is simpler to detect
  - ➔All “Hardware” checking logic
  - ➔No Software





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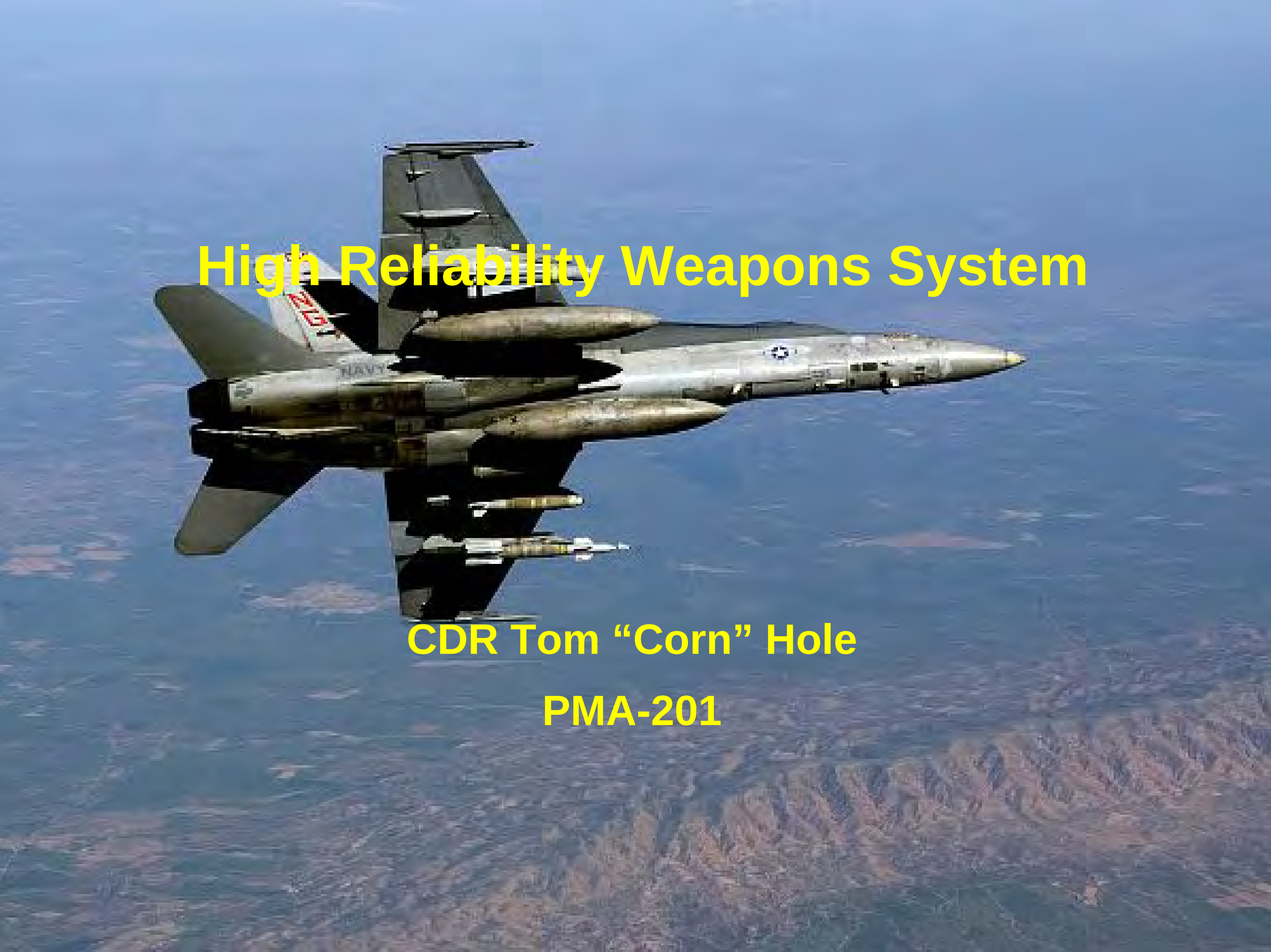
THALES MISSILE ELECTRONICS LIMITED

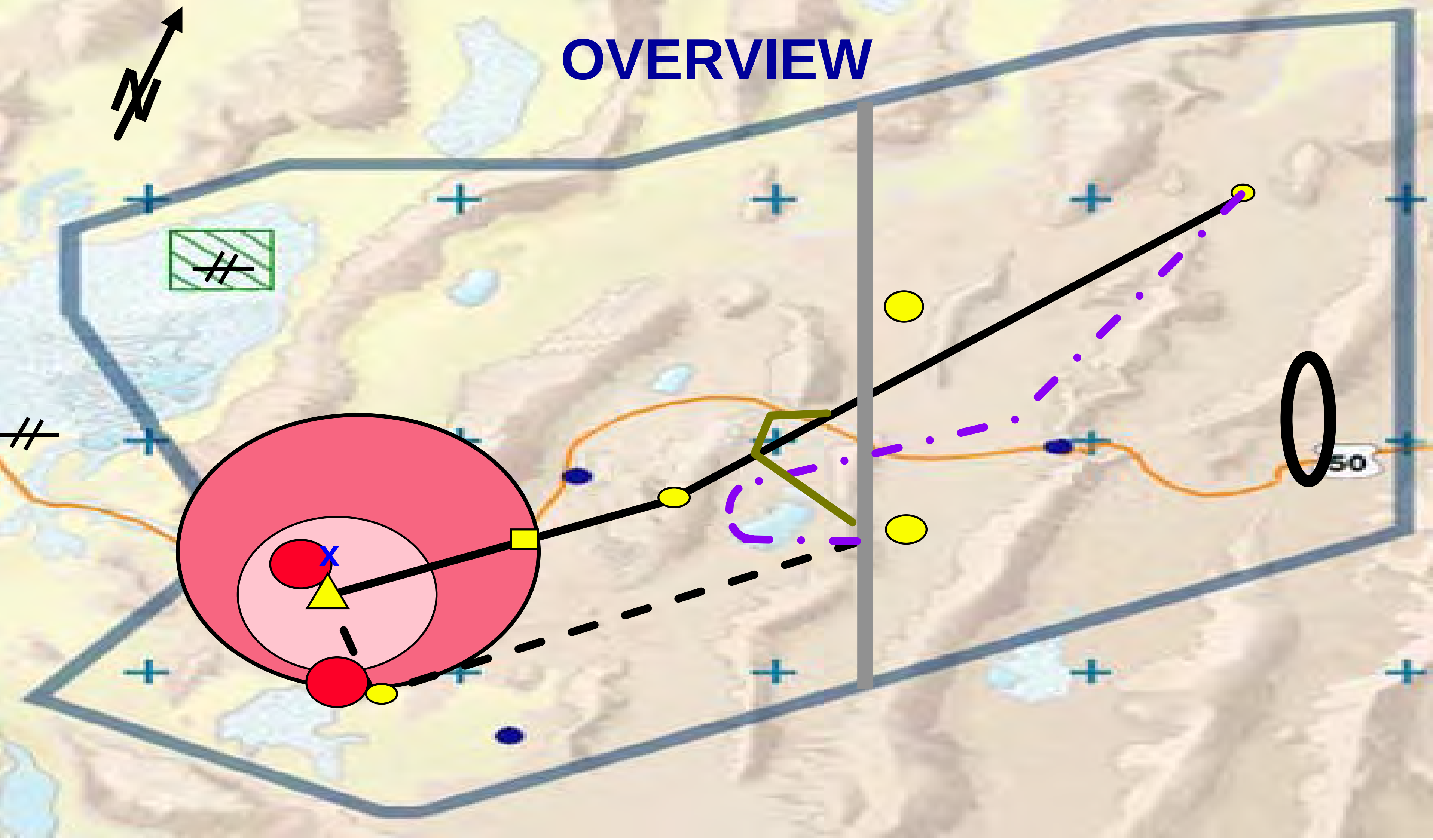
High Reliability Weapons System



CDR Tom “Corn” Hole

PMA-201

OVERVIEW



STRIKE COMPOSITION

(Desert Storm)

CALL SIGN		AIRCRAFT	MISSION	ORDNANCE
HAMMER	01	FA-18	STK/FTR	8xMK83
“	02	FA-18	“	“
“	03	FA-18	“	“
“	04	FA-18	“	“
“	05	FA-18	“	“
“	06	FA-18	“	“
“	07	FA-18	“	“
“	08	FA-18	“	“
NAIL	41	FA-18	STK/FTR	“
“	42	FA-18	“	“
“	43	FA-18	“	“
“	44	FA-18	“	“
“	45	FA-18	“	“
“	46	FA-18	“	“
“	47	FA-18	“	“
“	48	FA-18	“	“
SWEEP	11	FA-18	CL. ESCORT	1/2/3
“	12	FA-18	“	“
“	13	F-14	“	2/2/2
“	14	F-14	“	“
“	15	FA-18	“	1/2/3
“	16	FA-18	“	“
“	17	FA-18	“	“
“	18	FA-18	“	“
TRON	07	EA-6B	JAM	1xAGM88
“	17	EA-6B	“	“
TRON	20	FA-18	HVAAP	1/2/3
“	21	FA-18	“	1/2/3
ZAP	22	FA-18	HARM	3xAGM88
“	23	FA-18	“	“
“	24	FA-18	“	“
“	25	FA-18	“	“
SNOOP	26	S-3	ES	
RAVEN	27	ES-3	ES	
DOME	01	E-2	C2	
DOME	02	E-2	C2	

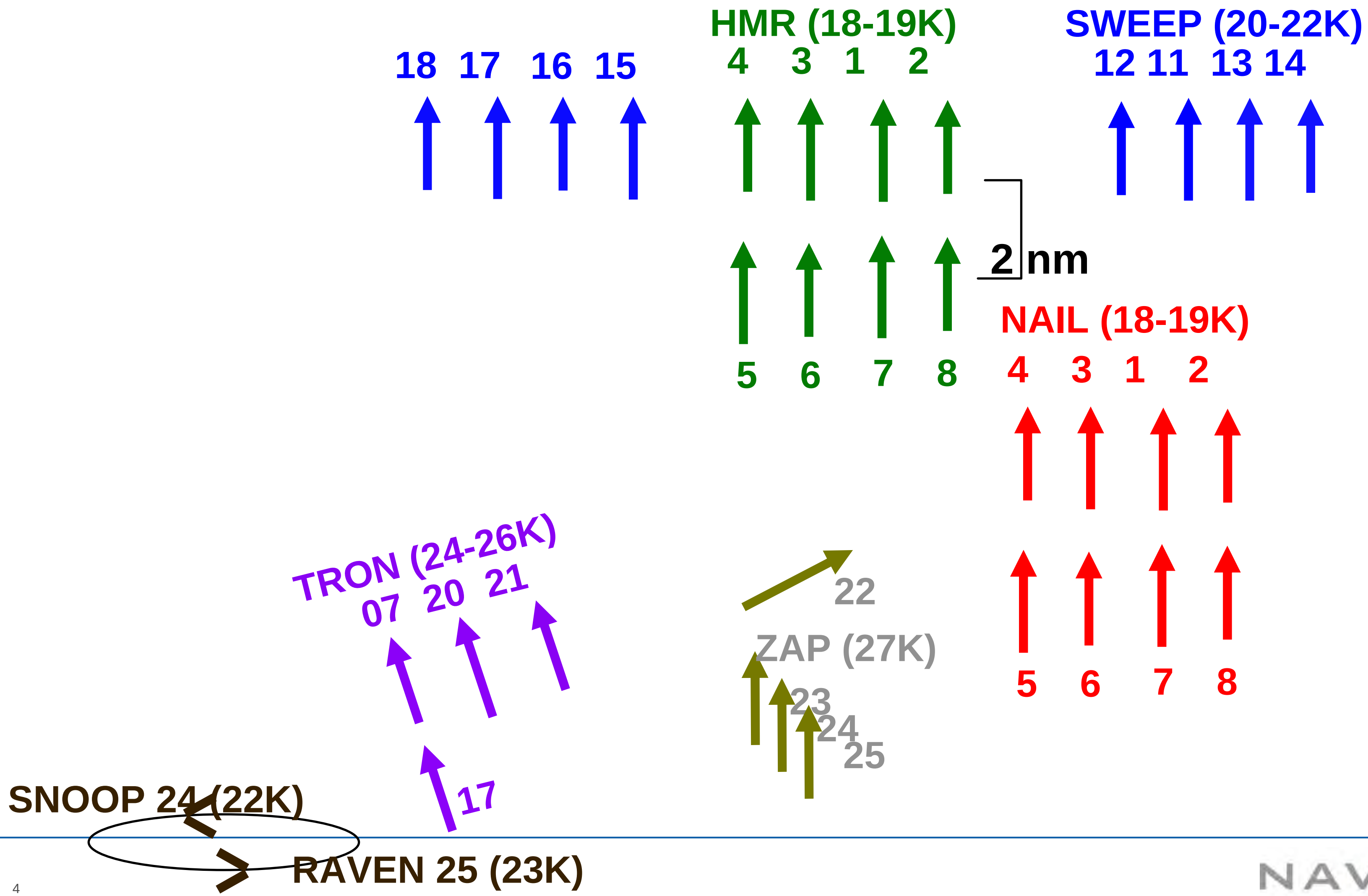
To prosecute 16 DMPIs requires:

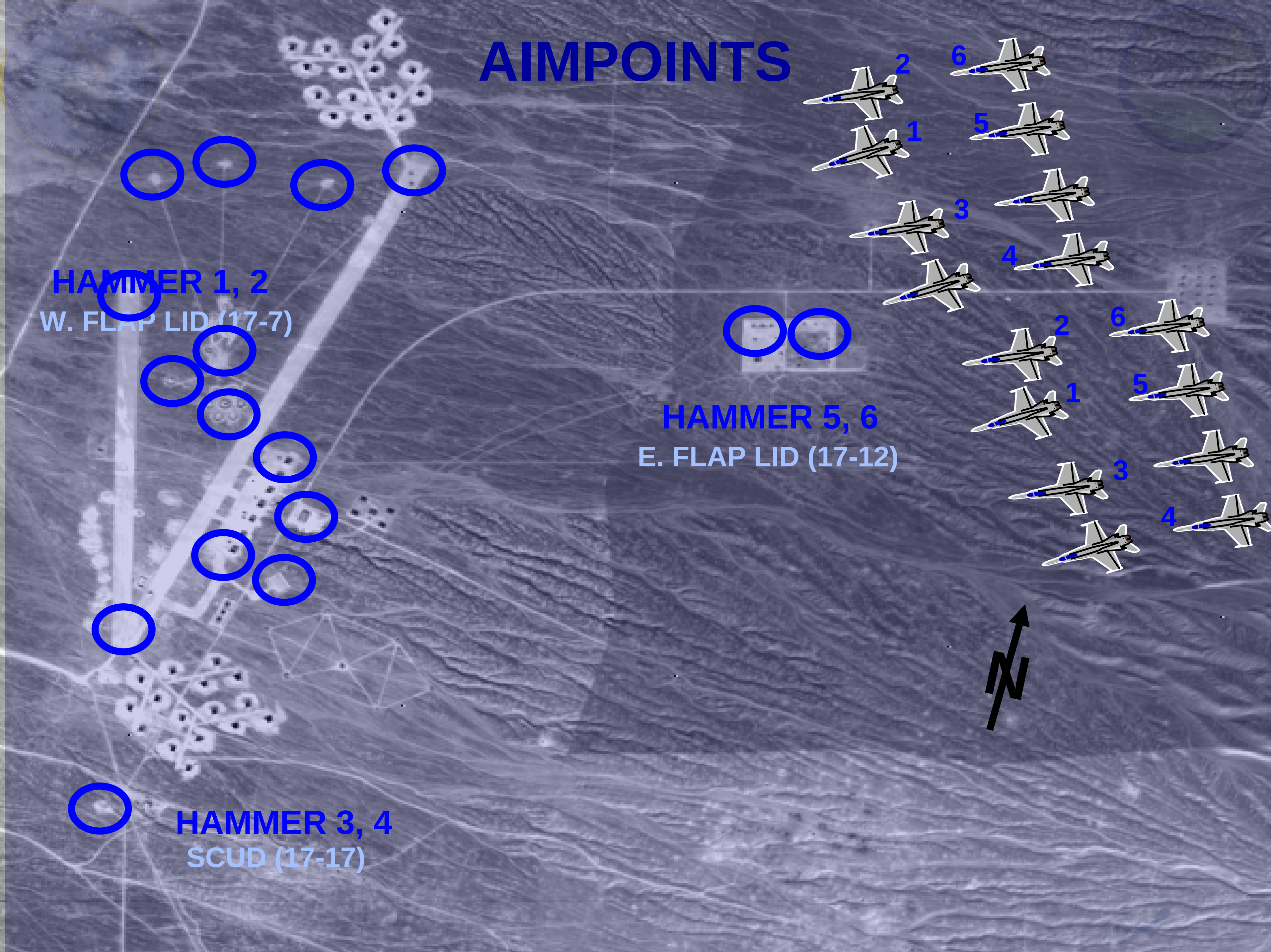
128 GP weapons

16 Strike Aircraft
20 Support Aircraft
36 Total Aircraft

NAVAIR

FORM SNAPSHOT





AIMPOINTS
HAMMER 1, 2
W. FLAP LID (17-7)
HAMMER 5, 6
E. FLAP LID (17-12)
HAMMER 3, 4
SCUD (17-17)
2
6
1
5
3
4
2
6
1
5
3
4
N

STRIKE COMPOSITION

CALL SIGN		AIRCRAFT	MISSION	ORDNANCE
HAMMER	01	FA-18	STK/FTR	4 x JDAM
"	02	FA-18	"	"
"	03	FA-18	"	"
"	04	FA-18	"	"
SWEEP	11	FA-18	CL. ESCORT	1/2/3
"	12	FA-18	"	"
"	13	F-14	"	2/2/2
"	14	F-14	"	"
TRON	07	EA-6B	JAM	1xAGM88
TRON	20	FA-18	HVAAP	1/2/3
"	21	FA-18	"	1/2/3
ZAP	22	FA-18	HARM	3xAGM88
"	23	FA-18	"	"
RAVEN	27	ES-3	ES	
DOME	01	E-2	C2	

To prosecute 16 DMPIs requires:

16 PGMs

4 Strike Aircraft
11 Support Aircraft
15 Total Aircraft

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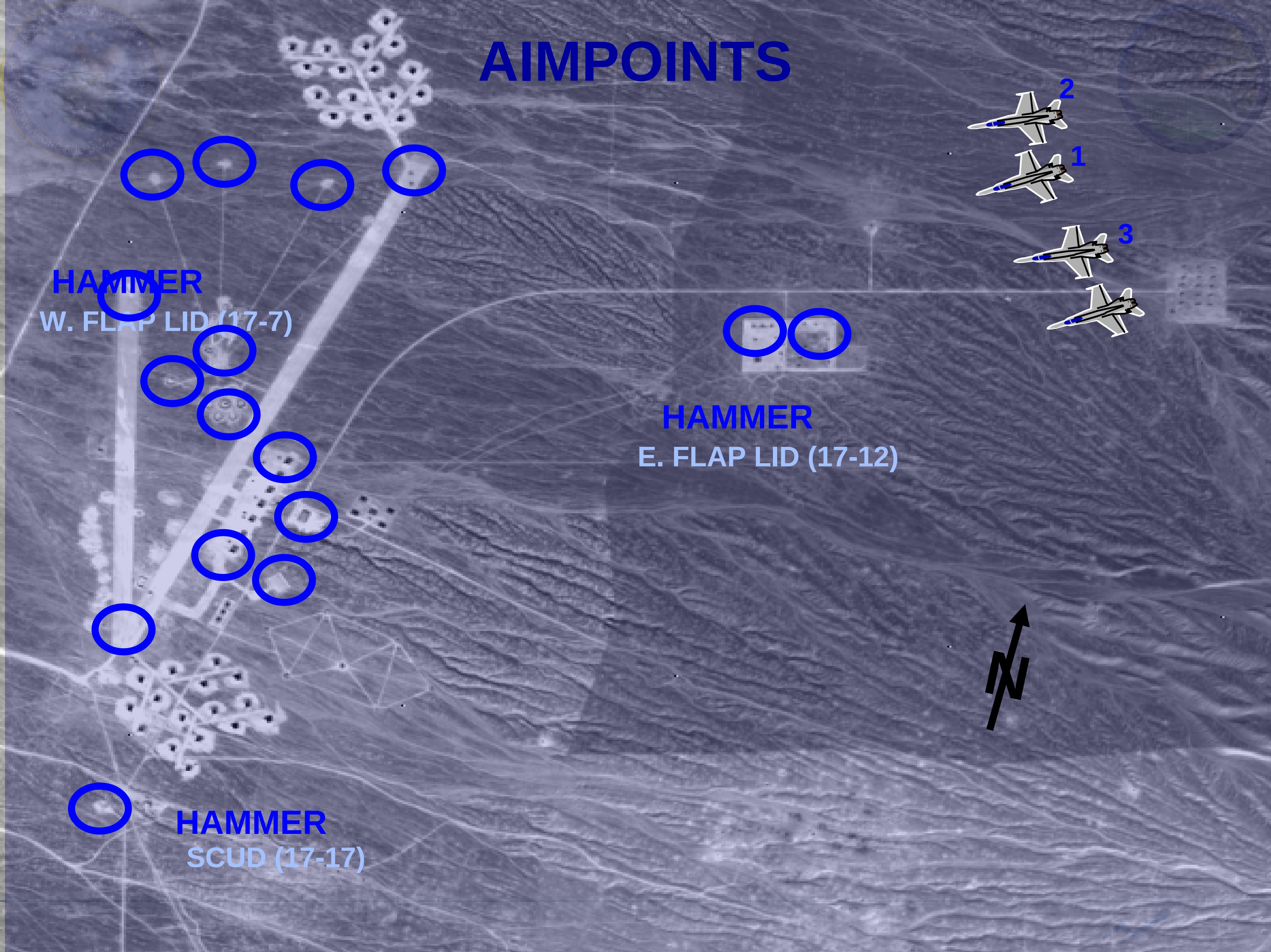
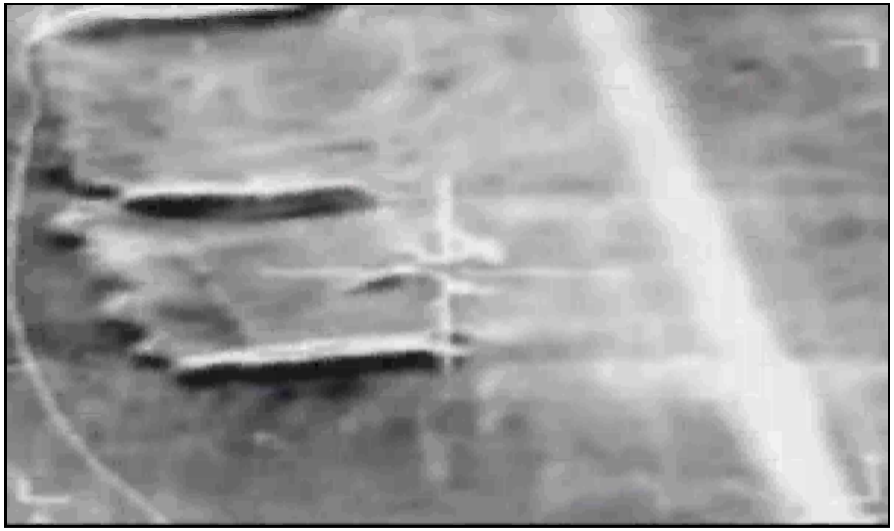

AIMPOINTS
2
1
3
HAMMER
W. FLAP LID (17-7)
HAMMER
E. FLAP LID (17-12)
HAMMER
SCUD (17-17)
N



Click box to run video.

Precision Revolution

- **Desert Storm**
  - Approximately 100,000 weapons delivered by TACAIR assets
  - 93% were unguided
  - 7% were precision guided
- **OEF / OIF**
  - Approximately 25,000 weapons delivered by TACAIR to date
  - 85% were precision guided
  - 15% were unguided

One bomb, One DMPI

How Does This Apply to Fuzes?

- **Duds are bad**
  - Target not destroyed
  - Troops in contact remain in contact (threat not destroyed)
  - Bad guys send the dud back to us as an IED
  - EOD must safe / remove dud

None of these results are good

Theoretical Fuze Reliability

Human Factor	Fuze Function Control Set	MK-122 Switch	FMU-139 FMU-152	Rel of Bomb Functioning
.85 to 1.0	.98 (spec)	.98 (spec)	0.95 (spec)	0.77 to 0.91

- Current MATHMATICAL RELAIBILITY, according to spec, best case:
  - **93% reliable (FFCS mode)**
  - **90% reliable (FZU mode)**
    - FZU-48 spec reliability is 95% vs FFCS spec reliability of 98%

This is what DoN paid for: 93% best case reliability

NAVAIR

Fuze Improvement Status

- **FMU-139C/B**
  - Adds 4 minute life with FFCS
  - Retains electro-mechanical safe arm device
  - No improvement in reliability
- **FMU-152 (JPF)**
  - Adds serial data interface to electro-mechanical safe arm device
    - Allows cockpit selectable arm/delay times
  - No improvement in reliability vs FMU-139
- **FMU-139D/B**
  - Electronic Safe Arm Device
  - Improves fuze reliability to near 100%
  - Allows further improvement in overall system reliability not possible with current fuzes

Theoretical Fuze Reliability

Human Factor	Fuze Function Control Set	MK-122 Switch	FMU-139 FMU-152	Rel of Bomb Functioning
.85 to 1.0	.98 (spec)	.98 (spec)	0.95 (spec)	0.77 to 0.93

- Current MATHMATICAL RELAIBILITY, according to spec, best case:
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This is what DoN paid for: 93% best case reliability

Hi-Rel Program

- **The first time you know if an FMU-139 or FMU-152 is going to work is when it hits the ground**
- **Goal of HiRel is to provide high reliability weapons SYSTEM**
  - Computers talking to computers
    - Eliminates current electro-mechanical fuze designs
  - 1760 interface allows system to identify failures BEFORE the bomb is released
  - Improves / Eliminates points of failure
    - FZU
    - MK-122
    - Cables
    - Connectors
  - Greatly simplifies assembly and load process

Improve OVERALL Fuze System Reliability to near 100%

Hi-Rel Program

- **DoD can't afford 100% inherent reliability**
- **BIT and status monitoring can be just as effective**
- **Example:**
  - 100 bombs dropped, 5 duds = bad
  - 95 bombs dropped, 0 duds = good
- **If we can achieve 85% reliability measured before the weapon is dropped but every weapon works 100% of the time when viewed by the bad guys, this is a good thing**

Reliability is measured at the target

Words from the War

"My concern is that this war has reached a point where a tactical error can have strategic implications so everything in our arsenal needs to work first time, every time. We have also become the victim of our own success in that the ground troops "know" we can shack the target every time and pretty much control collateral damage. As such, we only drop one at a time so when one doesn't work as advertised it becomes obvious."

- ***Lt Gen Walter Buchanan***

Commander of 9th Air Force

Current Weapons Reliability Requirement = 100%

Summary

- One bomb, one target
- 100% is the requirement
- System of Systems approach


Questions?

Abstract

Abstract: The FMU-139 and FMU-152 (JPF) are currently used in USN and USAF general purpose bomb based weapons to include JDAM, Laser Guided Bombs (LGB) and Dual Mode Laser Guided bombs (DMLGB). The demonstrated reliability of the FMU-139/152 in combat operations has been at or near 95%. The operational commanders have expressed that this is not acceptable and they require a weapons system that is 100% reliable. Any duds result in coalition forces being held at additional risk or the dud bomb being utilized as an IED by enemy forces. Just as the GPS weapon transformed our concept of one weapon, one kill, this same transformation has led to the requirement for 100% reliability. To be more precise, every weapon that is released must detonate.
In order to achieve this level of performance, the current GP bomb fuzes must be transitioned to electronic safe arm devices. In addition, a system of systems approach to reliability and safety must be implemented. This is the approach that is being utilized in the High Reliability Weapons programs. This brief will cover the history, requirement and program the US Navy has implemented.

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Thermal Battery Development – Reduced Product Variability Through Six Sigma and Materials Finger-Printing

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Agenda

- Overview
  - Thermal Batteries and Applications
- Performance Comparison
  - Thermal Batteries Versus Ambient Temperature Batteries
- Process Definition Using Six-Sigma
- Thermal Battery Description
- Manufacturing Processes
  - Process & Materials Control
  - Materials Characterization
- Cost Reduction Initiatives
- Benefits of End-Product Consistency
- Summary

Overview

- Thermal Batteries are used on a variety of weapon systems, including:
  - Bombs
  - Projectiles
  - Missiles, etc.
- Proper battery function is often of critical importance in meeting a weapon system's mission requirements.

CALCM

ERGM Projectile

- Thermal batteries have a proven track record and are capable of meeting the most demanding requirements.

M830A1

Overview

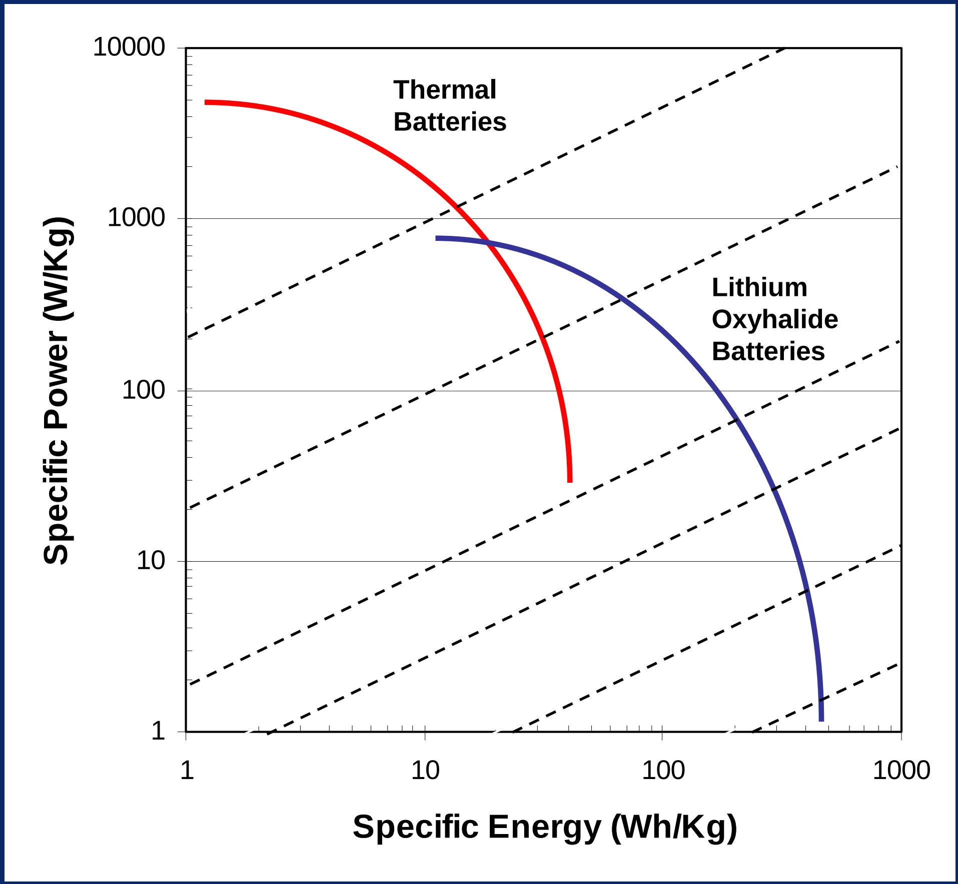
- Correct battery function depends on its design and manufacture, both of which present some challenges.
  - Design subtleties affecting performance can be overcome using test verification
  - Manufacturing or materials subtleties, on the other hand, often cause issues even after they were thought to have been taken care of.
- This paper presents a thermal battery development effort where product variability is reduced through the use of six-sigma tools, materials characterization or “finger-printing”, and automation.
- The battery developed by this effort can be used on several applications, including the DSU-33 Proximity Sensor and the Precision Guided Mortar Munition (PGMM).

PGMM

DSU-33 Proximity Sensor

Performance Comparison

- Certain battery systems are ideally suited to military applications.
  - Cold Operating Temp. (-45F)
  - Long Shelf Life (>20 years)
- Lithium Oxyhalide Batteries are best suited to applications that require extended life.
  - Lithium/Thionyl Chloride
  - Lithium/Sulfuryl Chloride
  - Lithium/Sulfur Dioxide
- Thermal Batteries are best suited to applications that require high power.
  - Lithium Silicon/Iron Disulfide
  - Lithium Silicon/Cobalt Disulfide



Ragone Plot Comparing Thermal Batteries to Lithium Oxyhalide Batteries.

(Approximate data - plot for illustration purposes only)

Performance Comparison – General Features

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Parameter	Thermal Batteries	Lithium/Oxyhalide Batteries
Description	Self-contained, hermetic, electrochemical power source	Self-contained, hermetic, electrochemical power source
Storage Life	20 years	20 years
Storage Mechanism	They achieve dormancy by utilizing electrolytes which require elevated temperature to become ionically conductive.	They achieve dormancy by physically separating the active components, i.e., the lithium foil anode and the electrolyte (catholyte).
Strength	Provide **high current** density for high power applications.	Provide **high energy** density for extended mission times
Reliability	High	High
Thermal Management	Important design consideration	Minimal issues
Cost	Moderate to high	Low to Moderate – cost effective in high volume production

Performance Comparison

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	Ambient Temperature Batteries			Thermal Batteries	
	Lithium Metal / Thionyl Chloride ($Li/SOCl_2$)	Lithium Metal / Sulfuryl Chloride (Li/SO_2Cl_2)	Lithium Metal / Sulfur Dioxide (Li/SO_2)	Lithium Silicon / Iron Disulfide ($LiSi/FeS_2$)	Lithium Silicon / Cobalt Disulfide ($LiSi/CoS_2$)
Energy Density (Wh/kg)	Reserve: 50 to 150 Active: 300 to 440	Reserve: 45 to 135 Active: 265 to 387	Reserve: 32 to 95 Active: 200 to 280	Reserve: 20 to 45 Active: N/A	Reserve: 20 to 75 Active: N/A
Power	Moderate to High	Moderate to High	Moderate	High	High
Working Voltage Per Cell (Volts)	3.0 to 3.9	3.0 to 4.2	2.7 to 2.9	1.6 to 2.1	1.6 to 2.1
Temperature	-45F to +160	-45F to +160	-45F to +160	-45F to +160	-45F to +160

Process Definition Using Six-Sigma

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Concept Development

- Project Management (milestone planning, risk evaluation
- Voice of Customer
- Concept & Development
- Product Mapping

Product & Process Design

- DFM & DFA
- Process Mapping
- Design FMEA
- Process Capability
- Design of Experiments (DOE)

Product & Process Optimization

- DFM & DFA
- Process Design

Product & Process Capability

- Capability Analysis

Product Maturity

Thermal Battery Description

Concept Development → Product & Process Design → Product & Process Optimization → Product & Process Capability

G3190B1 Thermal Battery (DSU-33 Application)

Performance

Voltage (V): 22 to 32.0
Current (mA): 350
Rated Capacity (mAh): 20
Activation Time (ms): < 500
Initiation Approach: Electric Igniter
Operating Temp. Range (°F): -65 to +221
Storage Temp. Range (°F): -65 to +221

Physical Characteristics

Chemistry: $LiSi/FeS_2$
Size: 1.50” Dia. by 2.38” Length
Weight (g): 210

Environmental

MIL-STD-331 Environments

Thermal Battery Description

Concept Development → Product & Process Design → Product & Process Optimization → Product & Process Capability

- The G3190B1 device is a reserve primary lithium silicon/iron disulfide thermal battery.
- It is a self-contained, hermetic unit, capable of being stored in excess of 20-years and then being activated on demand.
- The battery's electrochemistry is based on Sandia's proven $LiSi/LiCl\text{-}KCl/FeS_2$ system.
- Overall Cell Reaction:

$$Li_4Si + FeS_2 \rightarrow 2Li_2S + Fe + Si \qquad (1.6V\ to\ 2.1V)$$

- This system easily meets both power and energy requirements of the DSU-33 fuze application.

Thermal Battery Description

LITHIUM ACTIVE RESERVE

ATK

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Concept Development → Product & Process Design → Product & Process Optimization → Product & Process Capability

LiSi/FeS_2 Battery for DSU-33

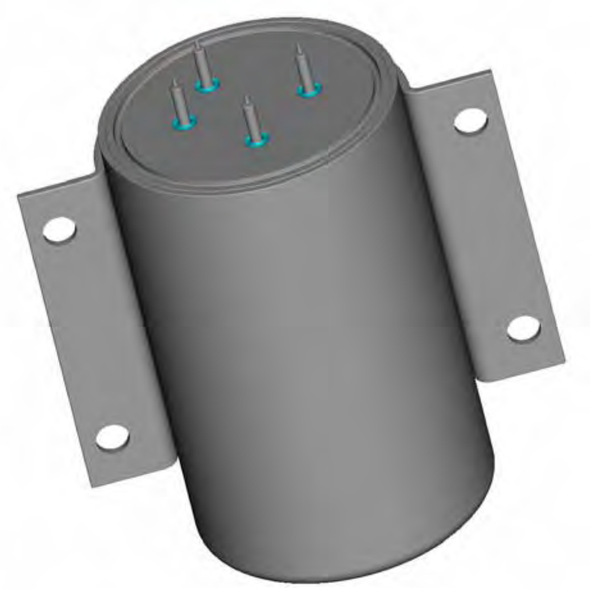
- Battery uses 15 cells in series
  - Voltage: 31.5V max.
  - Working voltage per cell: 1.8 V nom per cell
- Application requires a power of 7.7 Watts
  - Battery power significantly exceeds requirement due to the relatively high intrinsic electrode capabilities and battery size.
  - Initial battery projection approximately 150 watts.
- Application requires a capacity of 19.44 mAh
  - Battery capacity significantly exceeds requirement due to manufacturing limitations for minimum electrode thicknesses.
  - Initial battery projection 120 mAh capacity.

Thermal Battery Description

Concept Development → Product & Process Design → **Product & Process Optimization** → Product & Process Capability

LiSi/FeS_2 Battery for DSU-33

- Design uses a lithiated cathode to compensate for electro-active impurities.
- Electrolyte uses a eutectic binary composition of lithium chloride-potassium chloride to achieve lower temperature operation.
- Center fire initiation using an igniter.
- Operating Temperature Range: 352°C to 550°C.



G3190A1 Battery with Mounting Bracket

Manufacturing Processes

Concept Development → Product & Process Design → Product & Process Optimization → Product & Process Capability

Manufacture Components

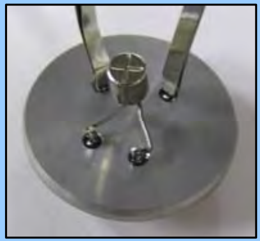

Heat Pellet


Anode Pellet


Separator Pellet

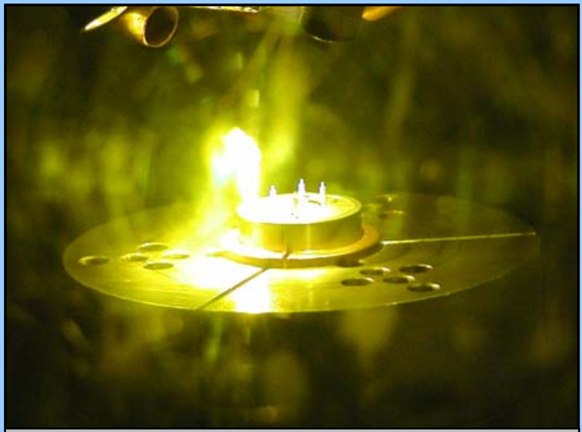

Cathode Pellet

Manufacture Subassemblies


TP/Igniter Assembly


Cell Stack Sub-assembly

Final Battery Assembly


Battery Closure Weld


Cut-away View of Thermal Battery

Process & Material Control

Concept Development → Product & Process Design → Product & Process Optimization → **Product & Process Capability**

Thiokol's "Fingerprinting" Program

- The diagnostic combination of analytical methods for detailed characterization of key materials

Value of a material fingerprint

- A fingerprint can be used to identify a material, to differentiate it from similar looking materials, or lead to its source
- Important for acceptance of materials, qualifying a change in a manufacturing process, location, or supplier

General Benefits of Fingerprinting

- Increases reliability and consistency of end product
- Fundamental understanding of critical materials
- Provides baseline chemical profile of materials in use
- Lot-to-lot consistency can be monitored and changes flagged
- Material changes can be traced to their source
- Acceptance testing for small supplier who cannot afford lab support
- Instills technical ownership for critical materials
- Enhance requalification of changes in vendor or production site
- Improved supplier relationship through data sharing
- Database available for failure analyses

LITHIUM ACTIVE RESERVE

Materials Characterization

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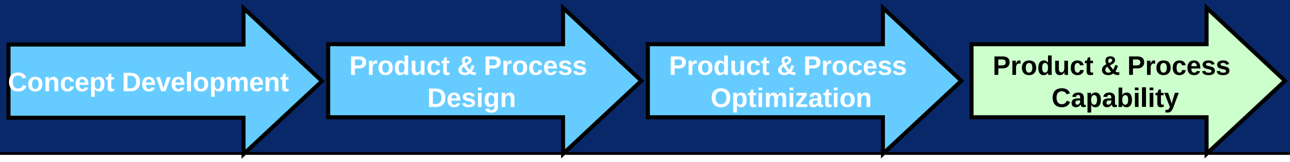
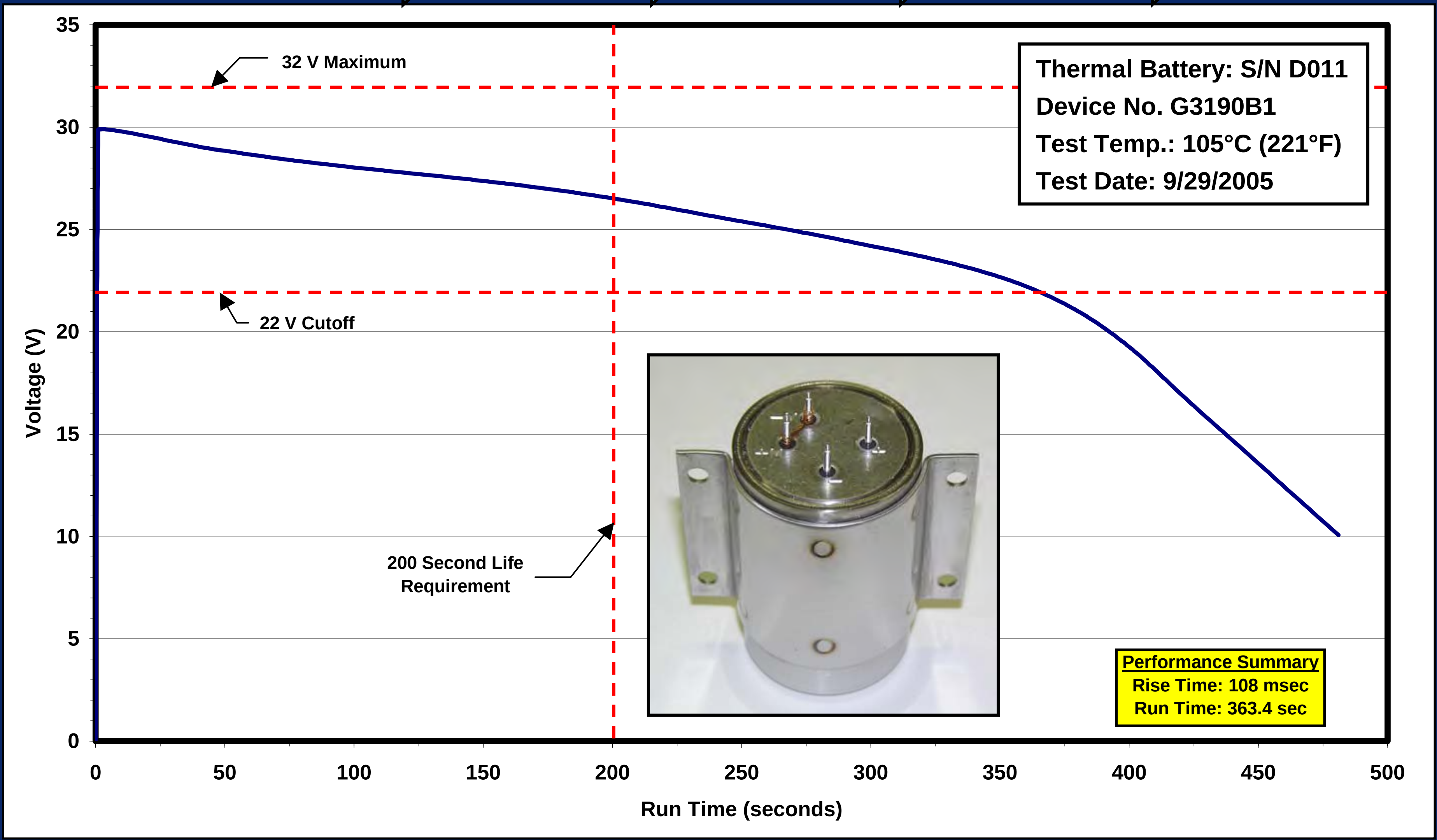
Concept Development → Product & Process Design → Product & Process Optimization → Product & Process Capability

Analytical Tests

Test	Description	Use
SEM	Scanning Electron Microscopy	Direct observation
Raman	FT - Raman Vibrational Spectroscopy – Laser Excitation	Identifies molecules
ICP/OES	Inductively Coupled Plasma with Optical Emission Spectroscopy Identification	Trace metal analysis
EDS	X-ray Diffraction Spectroscopy	Elemental composition
Metallurgical Analyses	Materials Analysis	Direct observation
Other Tests	Pyrotechnic Burn Rates Pressure Generation Versus Time Electrolyte Leakage Tests Mechanical Properties	Various

Performance





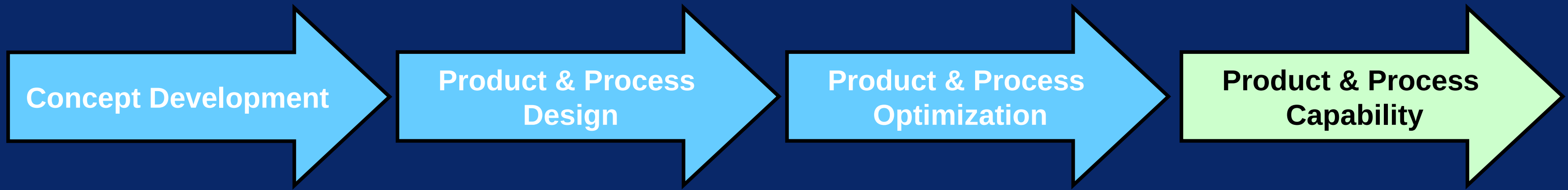
Cost Reduction Initiatives

An advanced weapon and space systems company

Concept Development → Product & Process Design → Product & Process Optimization → **Product & Process Capability**

- Automated Mechanical Press
  - High Speed Pressing of pellets
  - Smaller Footprint
  - Good Modularity for Changes in Pellet Size
- FeS_2 Purification
  - Safe & Cost Effective
- Lithium Silicon
  - Manufacture Versus Buy
- Igniters
  - Make/Buy Analysis has Identified Low-Cost Solution that Meets Requirements

Benefits of End-Product Consistency



- Increases product reliability
- Improves the consistency in performance, I.e., tighter groupings in performance
- Easier to identify technical issues

Summary

- A disciplined design and manufacturing approach using Six-Sigma tools has resulted in the success of this thermal battery project.
- Automated manufacturing of thermal batteries is long over due.
- Future power requirements appear to be headed toward higher energy and power densities:
  - Specific Energy: 35 Wh/kg → 70 Wh/kg
  - Specific Power: 750 W/Kg → 1500 W/Kg
- Technical innovations in both performance and manufacturing are required to meet the projected program demands.
- The ***Power Sources Center*** is poised and ready to take on these challenges.

NDIA Presentation

Proximity Fuze Branch

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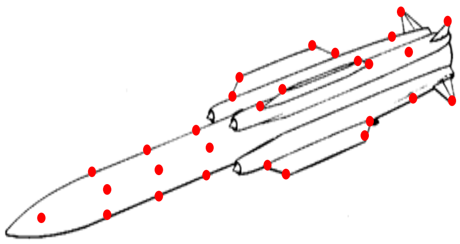
Proximity Fuze Simulation with Embedded Tactical Software



Approved for public release; distribution is unlimited.

GenSim Fuze Simulation (1995 – present)

- GenSim runs missile endgame scenarios and outputs data in many formats. (Radar Proximity Fuze Simulation written in MS Visual C++). It is primarily written in "C".
- GenSim utilizes actual radar patterns / gains and implements Npoint target modeling and simulated radar clutter modeling.
- GenSim actually moves a missile reference and target reference along vectors toward Point-of-Closest-Approach (PCA) in its calculations. (This is called Time-Based processing).
- GenSim presently has about thirty target models and variations of target models. It has missile AAW targets, surface targets, and slow targets. It contains a low altitude clutter model.

Missile Proximity Fuzing

- Missile proximity fuzing is implemented in the last moments of missile flight as the missile and target converge to Point-Of-Closest-Approach (PCA). Proximity Fuzing is about detecting the target and timing the bursting of the warhead to optimize warhead fragment placement on the target.

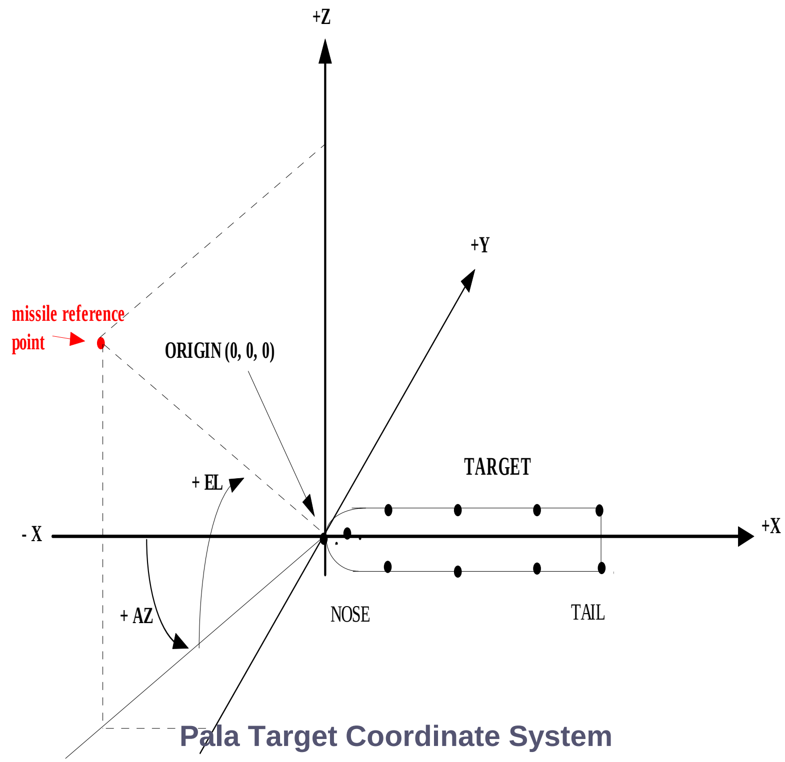
- The design of missile proximity fuzes (Target Detecting Devices (TDDs)) requires analysis tools that simulate the fuzing system's operation and measures of effectiveness for the TDD as well as the missile itself.

Legacy Fuze Simulations (1970 –1980's)

- Simple Geometric models: Event based, this means that the encounter did not actually move but detection was calculated geometrically.
- Slow: The computers these were run on were mainframes or mini-computers and took a long time to run encounter scenarios. Administration issues.
- Target and Clutter models were geometric models (or utilized tables of data, not actual sensor models)

Missile and Target Coordinates

GenSim fuze Detection is done in a Missile-Body Coordinate System. The fuze detection point is defined by a spherical coordinate R, α, ϕ

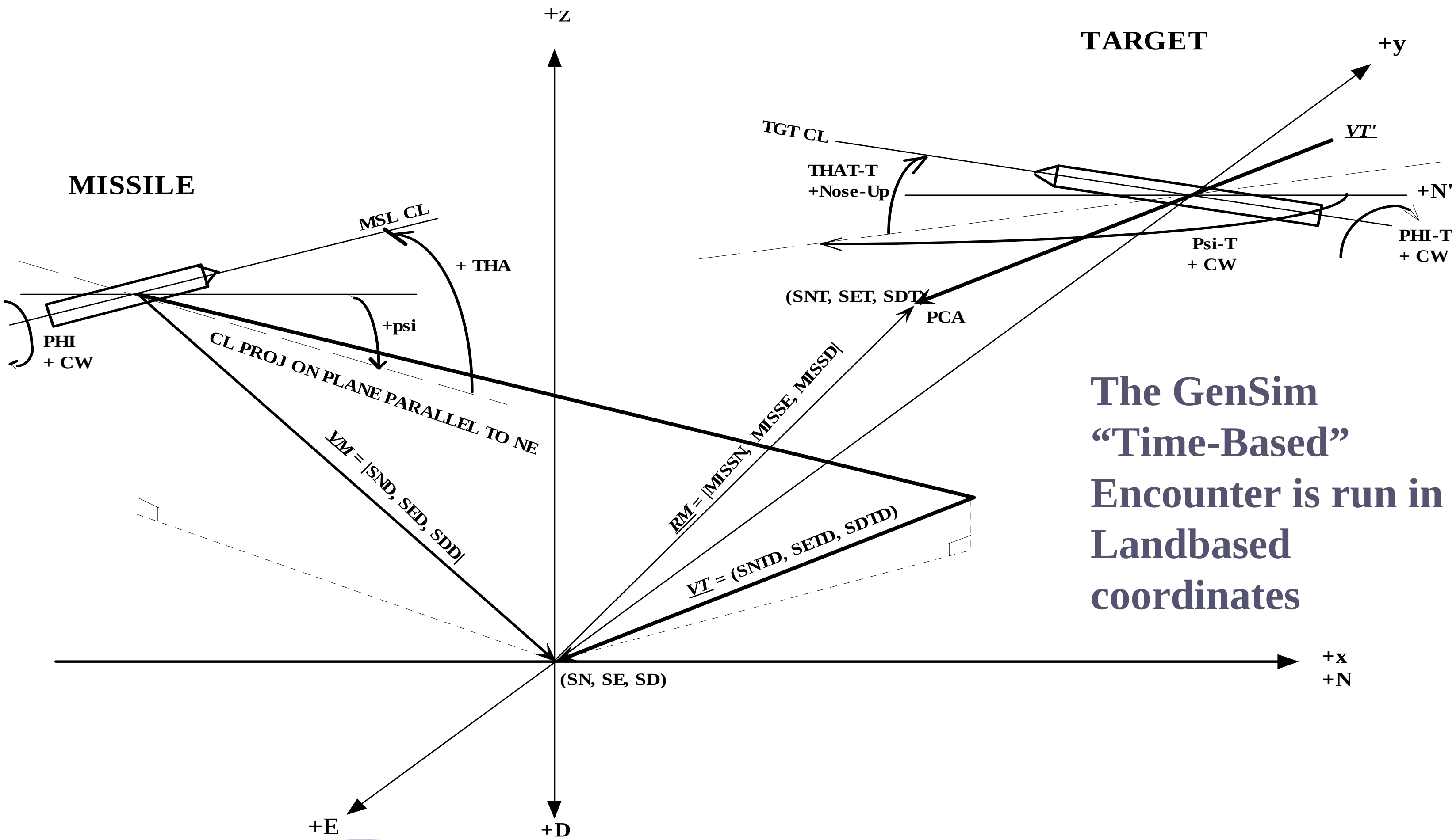


Pala Target Coordinate System

The Npoint Target is loaded into GenSim in Pala Coords.

Inertial Coordinates (Landbased)

Proximity Fuze Branch



The GenSim "Time-Based" Encounter is run in Landbased coordinates

GenSim Input / Output Files

Proximity Fuze Branch

SET → INPUT ENCS: EZE, 6DOF, MAG, OTHER

INPUT
ENCS:
EZE
6DOF
MAG
OTHER

FUZ
Gr,Gt,
Roll,Elv
DSP, Est

MSL
AOA, Beta
Spmiss. Est,
Whd tables

Target
xyz

Clutter
Mean, σ

I/O
Switches

GENSIM
***.EXE**

Target and
Clutter models

Detection And BurstControl
(TACTICAL SOFTWARE)

The output files include: Detect, No Detect, Guidance Reject, DR/XR, VM/X, Graph, Lethal Burst Interval, Banana, Mesa, Warhead Enc Format

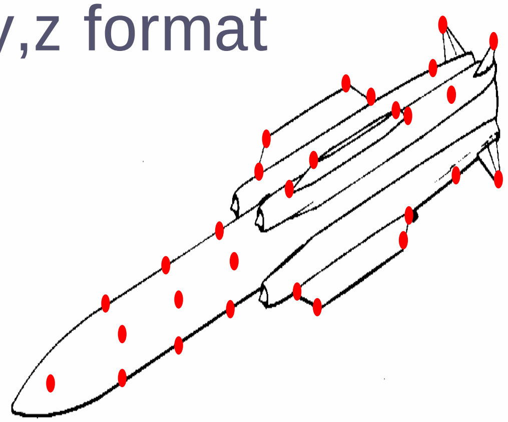
The SET file is run with GenSim and calls the files it needs to run

Switches include:
Output / Analysis folder.
Repeat Encounter, Clutter Rejection, Mirror,
Resp Est,
Detection Burst Cntl

Npoint Target Models

- An N-point model accounts for target RCS as well as radar characteristics, The "N" is the number of radar reflector points. N-point modeling is based on the theory that radar data tends to pool in specific areas on the target.
- Locations are specified relative to target nose (*.xyz file).
- The xyz file contains "N" points in x,y,z format
- The RCS specified in angle increments.
  - Az: -180 to +180.
  - El: -90 to +90.

At present there are over thirty N-point Targets developed for GenSim including Missiles, aircraft, slow targets and surface targets.



Clutter Modeling

- The GenSim Clutter Model loads an input file that contains the (Mean, σ) for Clutter Radar Cross Section (RCS) tabulated for various conditions and incidence angle of the beam.

- GenSim uses encounter geometry in looking up the (Mean, σ) value.

- The Threshold is calculated as:

$$RCS = Mean + K * \sigma + Offset:$$

where: Mean, σ are lookup table values.

Mean, σ, and Offset are in dBSm.

K and Offset are the clutter sigma multiplication factor.

Early GenSim / Fuze Algorithms

Proximity Fuze Branch

- GenSim was designed to do analysis "trade studies" for missile proximity fuze development.

- Early GenSim contained its own fuze detection and Burst Control. Burst Control contains time-delay algorithms.

- This simulation was used to make fuze design decisions in sensory development, signal processing complexity, and missile / fuze interface limits based on missile encounter conditions (to name a few).

- With the burst control software (guidance / fuzing / warhead combined effectiveness "PK" could be estimated).

Early GenSim / Common Header

- In early GenSim planning, it was intended that this simulation be implemented together with actual missile fuze tactical software to aid in improved tactical software development as well as provide “accurate” fuze effectiveness under varying missile endgame scenarios. GenSim would create the missile / target environment and would call the tactical software.

- To prepare for tactical software implementation a common header file “*.h” was created where both GenSim could place program definitions as well as the tactical software. This created a “common placeholder” where GenSim could pass and receive info from tactical S/W. Detection and BurstControl functions were defined with the prefix: “Common_” to prepare for Tactical implementation. The function“Common_DetTdLogic” contained GenSim detection and BurstControl algorithms.

GenSim, Early Tactical S/W

- For the first Tactical S/W interface, the "Common_DetTdLogic" function was replaced with a Tactical Interface (TI) function called "TI_TerminalExecutive( )". This file contains (GenSim/ Tactical) interface (TI) files.
- Other Tactical file definitions: "TI" was tactical interface,"LM" lightly modified tactical files, "SAL" were "Simulation Abstraction Layer" as opposed to the tactical "HAL" Hardware Abstraction Layer.
- The GenSim Side had to perform a lot of Tactical S/W initialization in the first implementation since the tactical software was not operating as it was designed. The tactical software was designed to run once. GenSim with embedded tactical must run multiple scenarios.

Early Tactical S/W (continued)

- GenSim is setup to run only the endgame portion of the encounter (last tenth of a second or so). The Tactical software is written to handle missile flight from intercept arm (last half second or so). GenSim has to properly handle the Tactical software for this part of the flight.
- GenSim would run the encounter and pass information to the Tactical S/W every frame while doing this pre-encounter initialization.
- In this early development our understanding of the Tactical S/W was poor and therefore our initialization methods were crude. The Tactical software was designed with microprocessors in mind and our embedded tactical simulation was not. The Dynamic-Linked-Library concept changed that.

GenSim Evolution (DLL's)

- In the Dynamic-Linked-Library approach, the Tactical Software becomes an Executable (*.exe) called by the GenSim Executable program. The Simulation becomes multiple nested executable programs that pass information through a mailbox (DLL).
- GenSim initializations can be done on the GenSim side, Tactical initializations can be done on the Tactical side and pertinent information can be passed between the processes through the DLL. The DLL approach simplified Tactical "drop-in" to GenSim.
- Before the DLL was utilized, GenSim would have to be run once for each processor in the system. (working with each processor independently). With the DLL concept, each processor is now an executable called by the GenSim executable each frame.

Fuze & Warhead Division

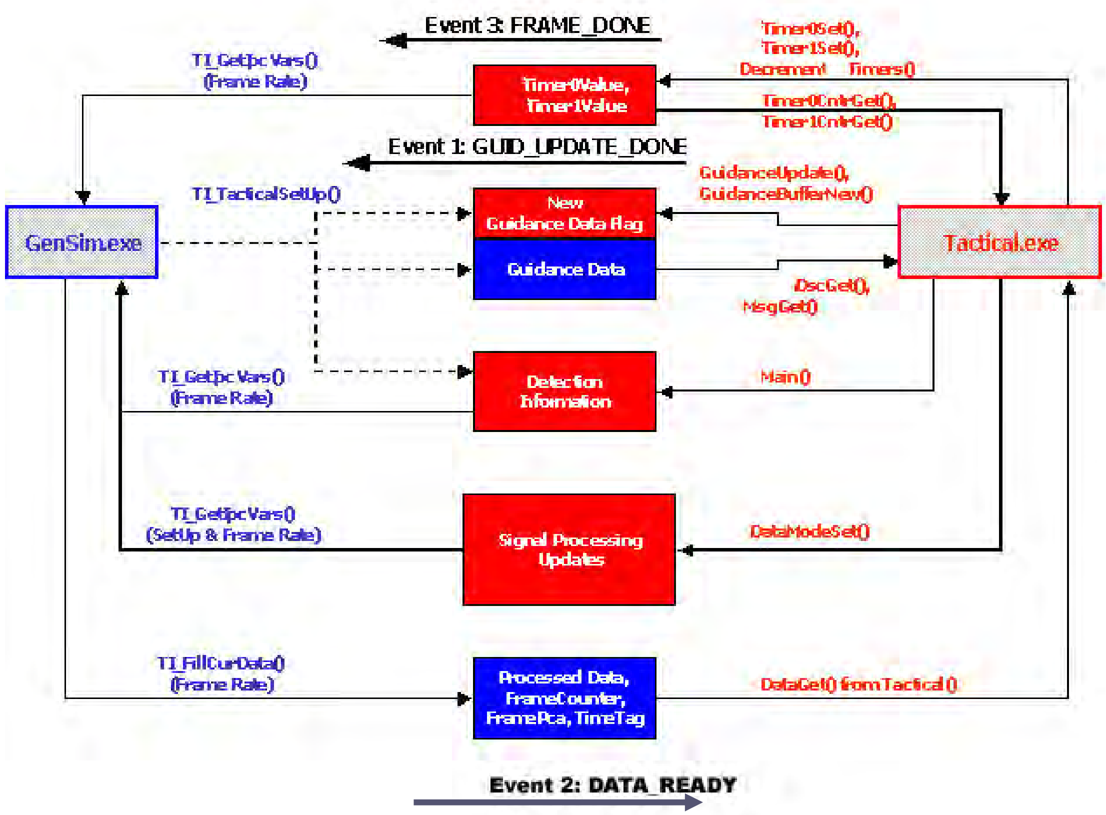
NAVAL AIR WARFARE CENTER WEAPONS DIVISION

NAVAIR

WEAPONS ENERGETICS DEPARTMENT

GenSim Evolution (DLL's)

Proximity Fuze Branch



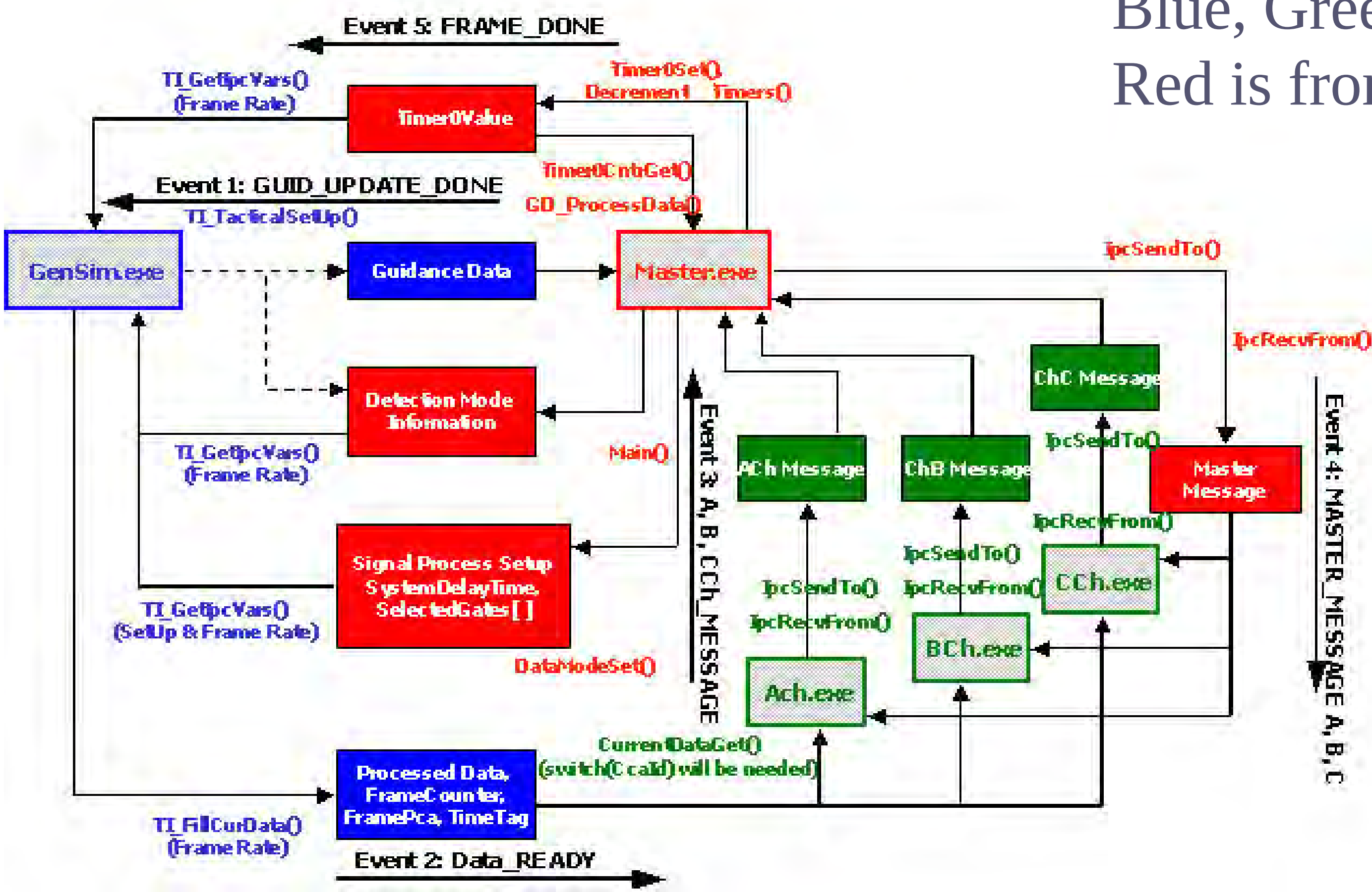
This figure shows a single processor, single executable DLL approach.

Red and Blue denote events where the DLL passes information between processors.

NAVAIR

GenSim Evolution (DLL's)

Proximity Fuze Branch



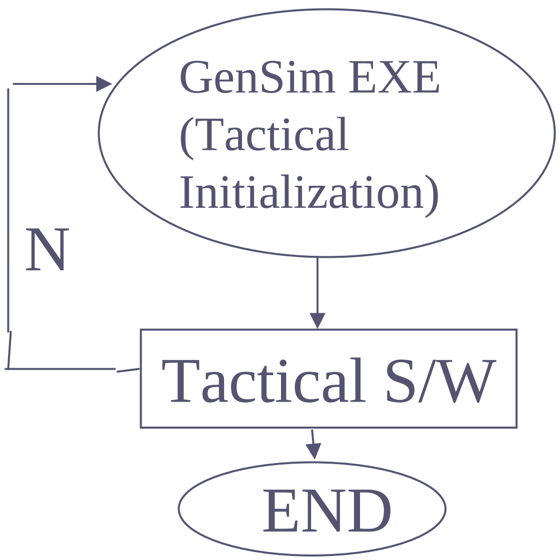
Blue, Green is To Master
Red is from Master

This figure shows a three processor, three executable DLL approach.

Red , Blue and Green denote events where the DLL passes information between processors.

GenSim Evolution (DLL’s)

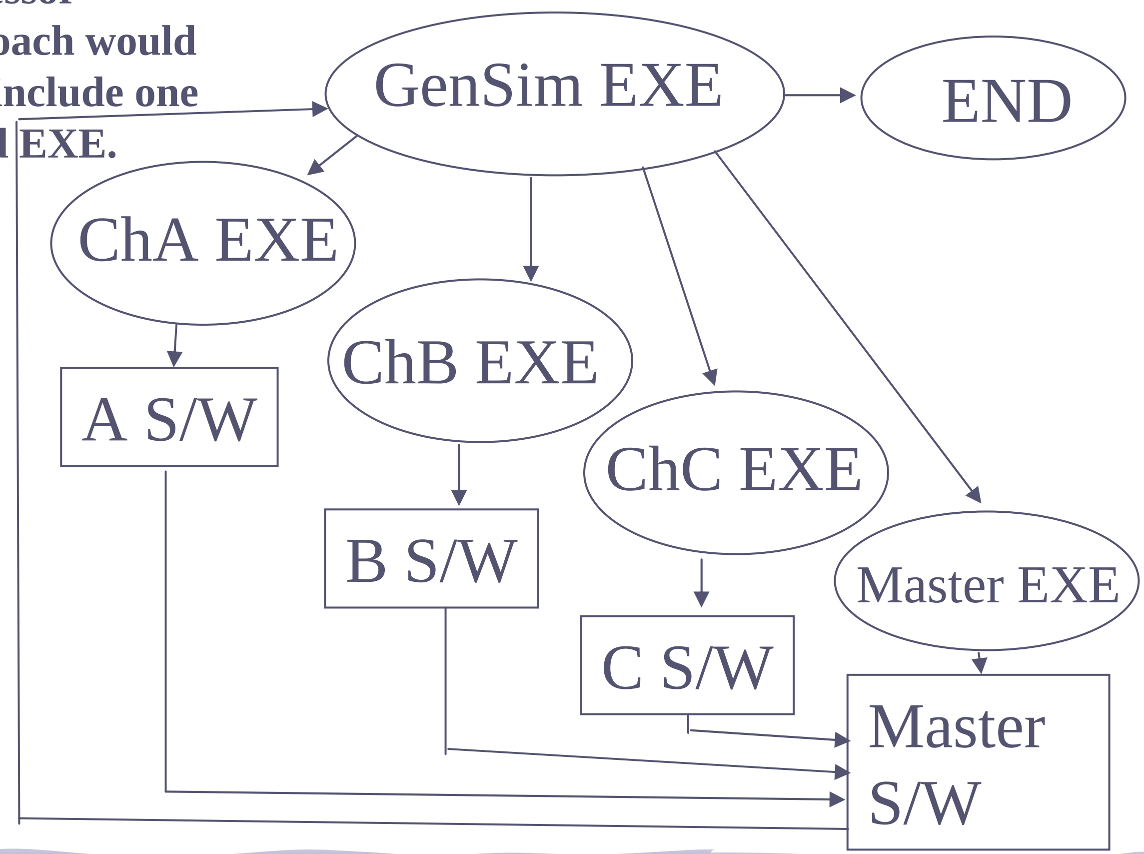
- Before DLL:



Run “N” times “N” being number of processors

Note the single processor approach would only include one called EXE.

DLL Version:



GenSim Used for Flight Testing

- GenSim can interface with missile six-degree-of-freedom (6DOF) files (two different file formats).

- 6DOF's can be run to simulate flight test conditions and the files run with GenSim to see how the fuze tactical software will respond to the flight test encounters.

- With this approach, we have been able to diagnose errors in the tactical software that have been fed back to the contractor for fixes. The new tactical software can then be put in the simulation and the process repeated. Flight Test TM data can be compared to simulation output data for post-flight analysis.

- This approach led to the improved DLL tactical software interface.

Notes and Comments

- By modeling Sensor TXT/RCV and Target reflectivity in the GenSim simulation we have a much improved simulation for doing missile fuze design verification and validation.

- Having the ability to “drop-in” a version of proximity fuze tactical software and run numerous tactical missile scenarios gives us an ability to find defects in the tactical software as well as predict tactical operation before any actual flight tests are performed. Post-Analysis with flight test TM can be compared.

- The Dynamic-Linked-Library (DLL) approach to interfacing the tactical software to the GenSim simulation simplified the interface, and improved the information handshake between GenSim and Tactical.

High-G Mortar Electronic S&A Demonstration

Presented by:
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Co-authors
Stewart Genberg
Calvin Cheung

Outline

- High-G ESAD Systems overview
- Project Team
- Technical Approach
- Design Details
- Testing and Results
- Current Status

Project Overview

- ARDEC ATO project to demonstrate high-g survivability of a potential low-cost electronic safety and arming device (ESAD) suitable for mortar and/or artillery fuzing.
- Both in-house and Kansas City Plant fireset designs to be evaluated as part of effort.
- Initial project to focus on demonstrating survivability for worst case mortar launch environment.
- Project to conclude with ballistic demonstration test at Yuma Proving Grounds on 81mm ammunition at Charge 4.

Project Team

Team Members

Stewart Genberg **–** Team Leader
ARDEC Fuze Division

Brian Mary – Lead Engineer
ARDEC Fuze Division

James Hartranft – Mechanical Engineer
ARDEC Fuze Division

Cuong Nguyen/ Calvin Cheung – Electronics Engineer
ARDEC Fuze Division

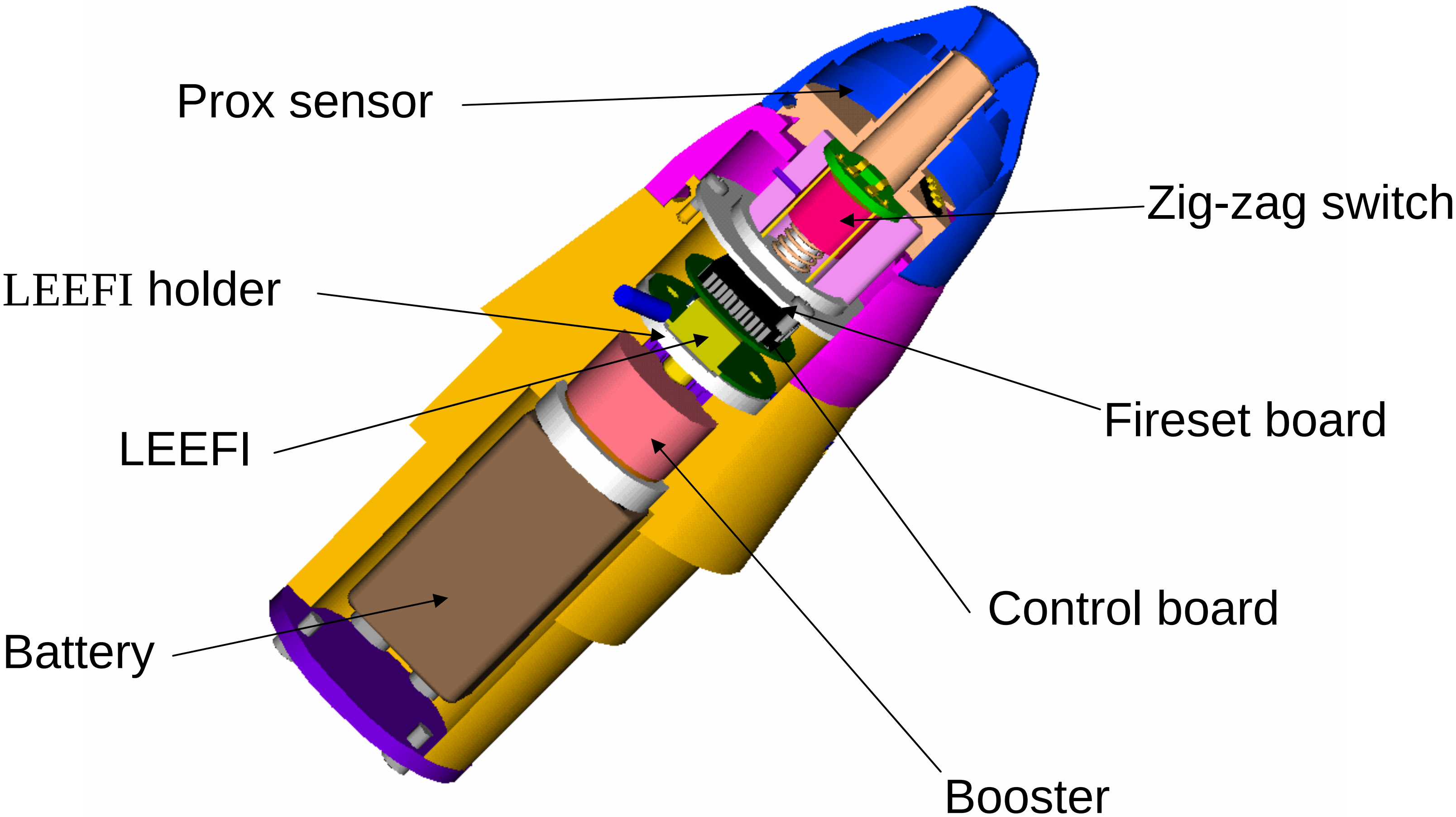
Technical Approach

- Microcontroller based Control Logic
- Standard ESAD architecture with two static arming switches and one dynamic arming switch.
- Custom zig-zag setback switch to sense first launch environment and act as one static arming switch.
- Second launch signature simulated with independent time-out circuit.
- Independent low energy fireset board assembly – two designs to be evaluated.

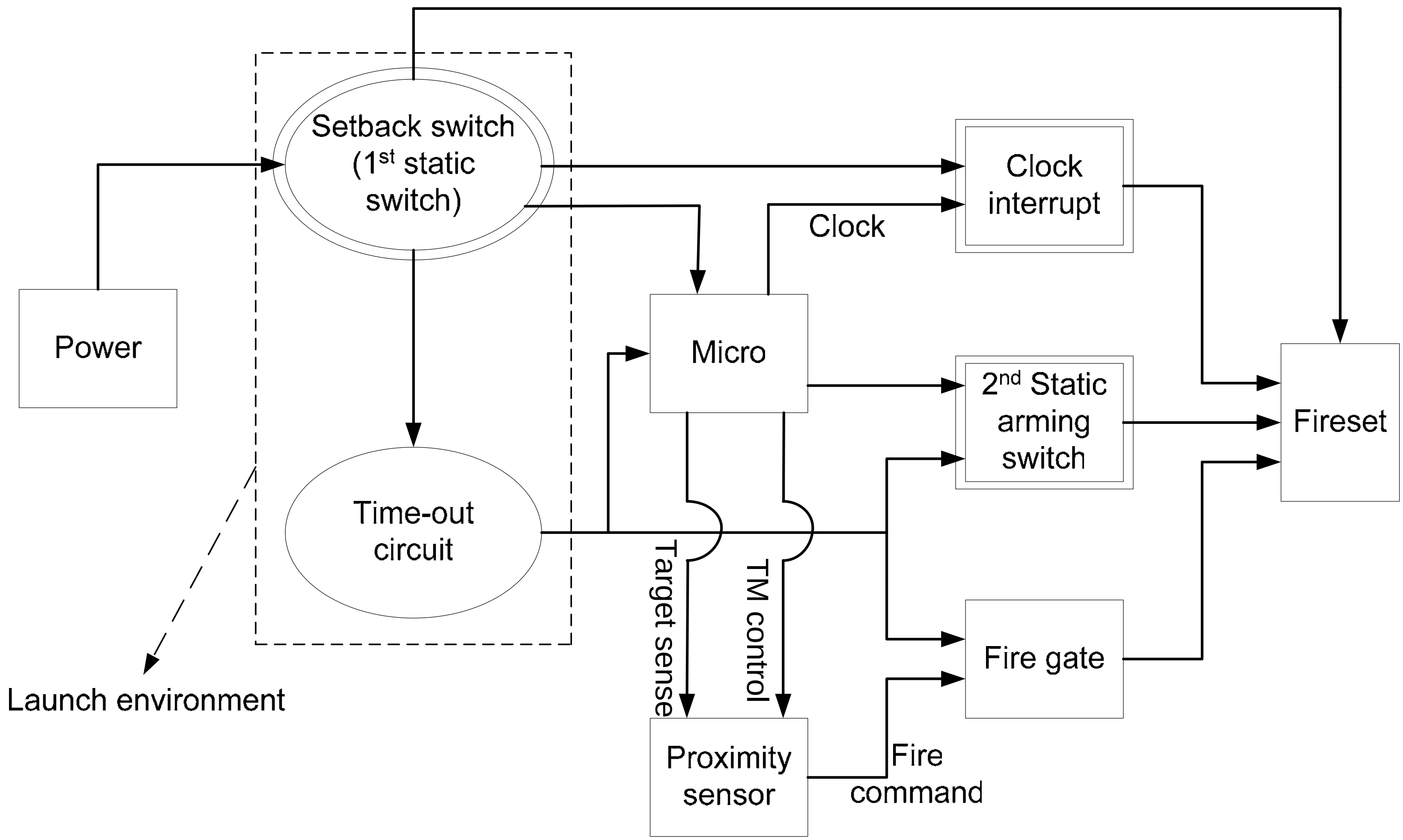
Technical Approach

- Modified M734A1 mortar fuze prox electronics for target detection.
- Standard LEEFI slapper detonator with RSI-007 output.
- M734A1 PBXN-5 Booster to be used in ballistic demonstration test for function signature.
- Repackaged off-the-shelf alkaline battery power supply

Device Drawing



Control Logic Block Diagram



Control Algorithm

- Pre-flight
  - Screw inserted in custom power switch to connect battery power
  - The micro will initialize and run a self-test to verify safe startup conditions
  - If all safety conditions are satisfied, the prox sensor transmits a code to indicate fuze is safe to fire.
  - If all safety conditions are not satisfied, the prox sensor will transmit fault codes signaling the error condition

Control Algorithm

- Launch and Flight
  - The micro remains in waiting state until zig-zag setback switch closes at gun launch
  - During flight, the fuze transmits self telemetry data
    - zig-zag closure
    - Time out delay completion
    - High voltage charge detection on fire capacitor
  - Self Telemetry data is transmitted on the down-leg of flight
  - Prox sensor provides fire command to fireset electronics at proper burst height.

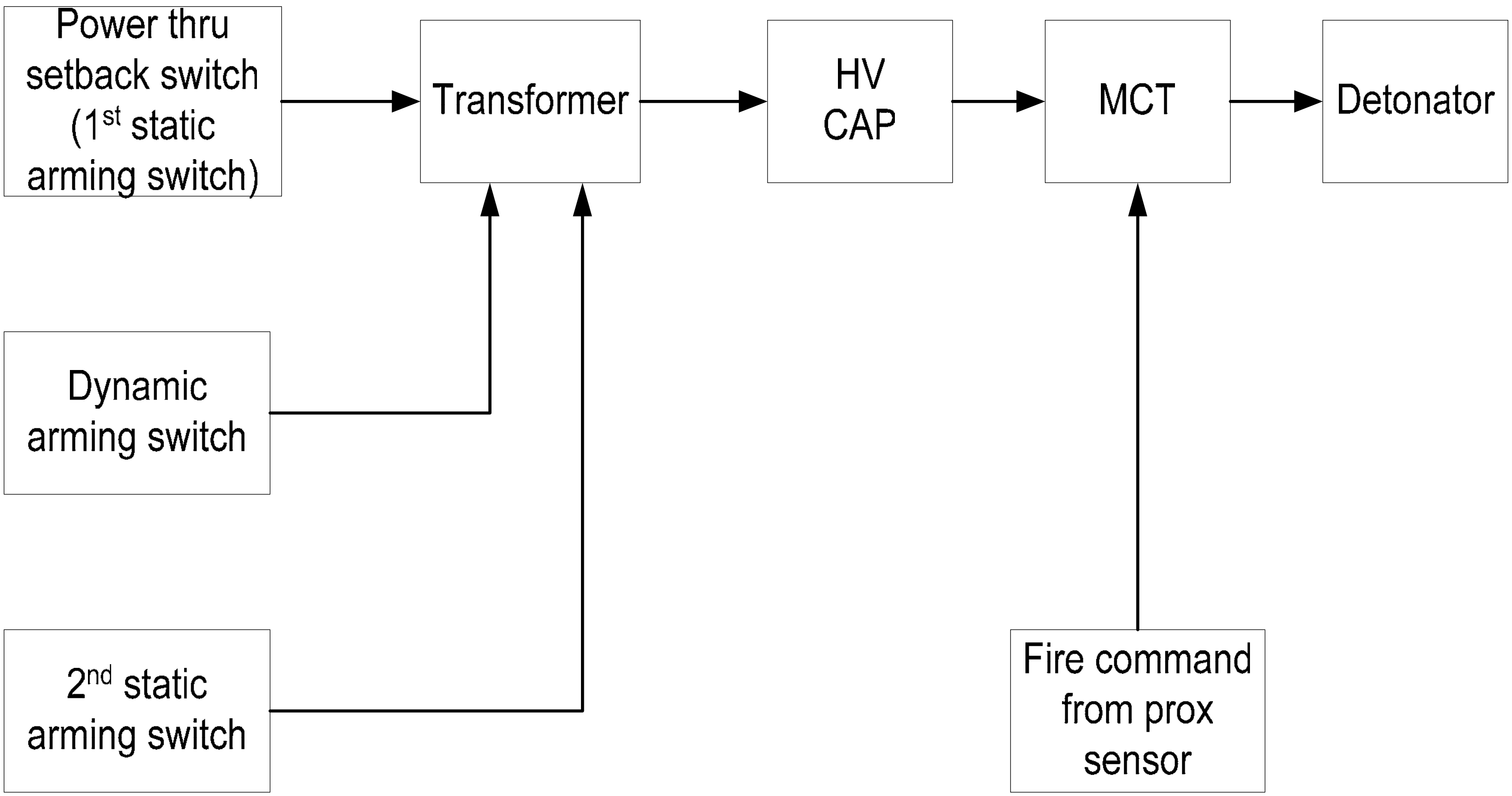
Firesets

- In-house fireset
  - Freq: 50KHz, 25% duty cycle
  - Charges 0.1µF capacitor to 1000V
  - Custom transformer winding

- Kansas City Plant MIF
  - Freq: 30KHz, 50% duty cycle
  - Charges 0.2µF capacitor to 1000V

- Same interconnection configuration

Fireset Block Diagram

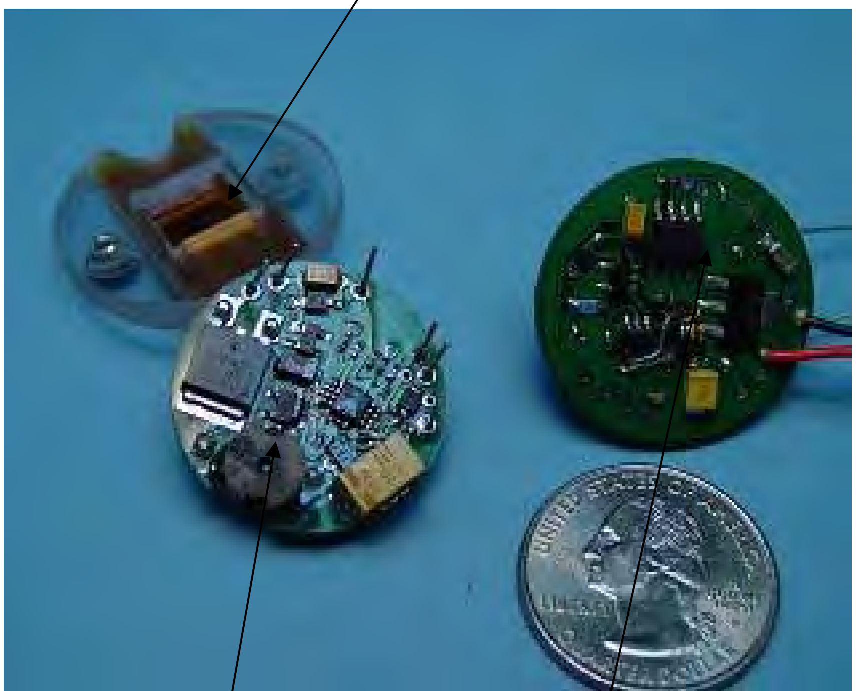


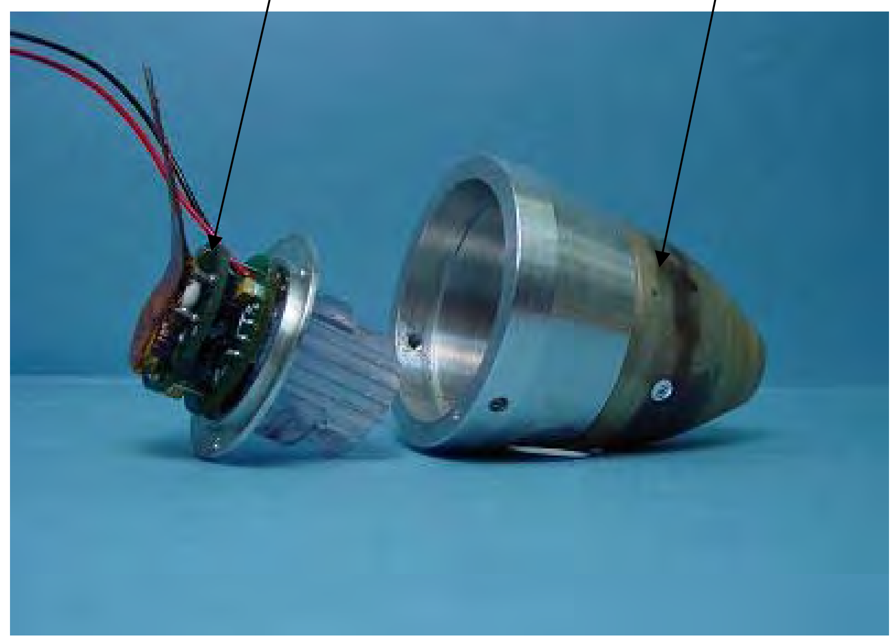
Electronics Hardware

LEEFI holder

Fireset board mated with Micro board

Prox sensor

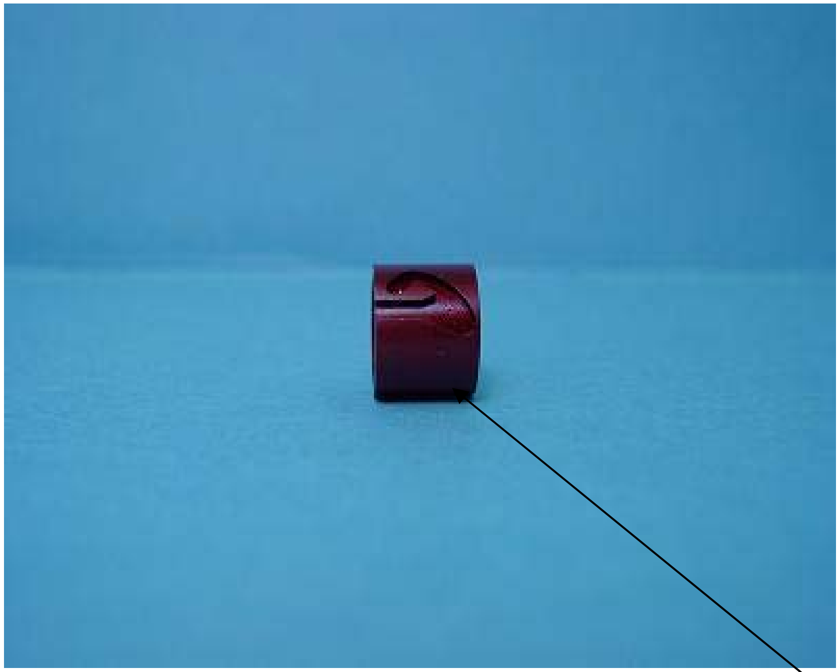


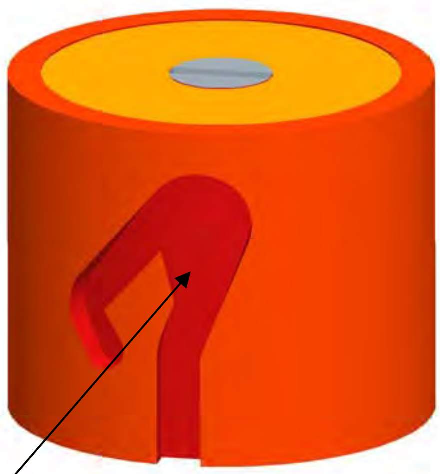


Micro board

In-house fireset

Electronic Hardware



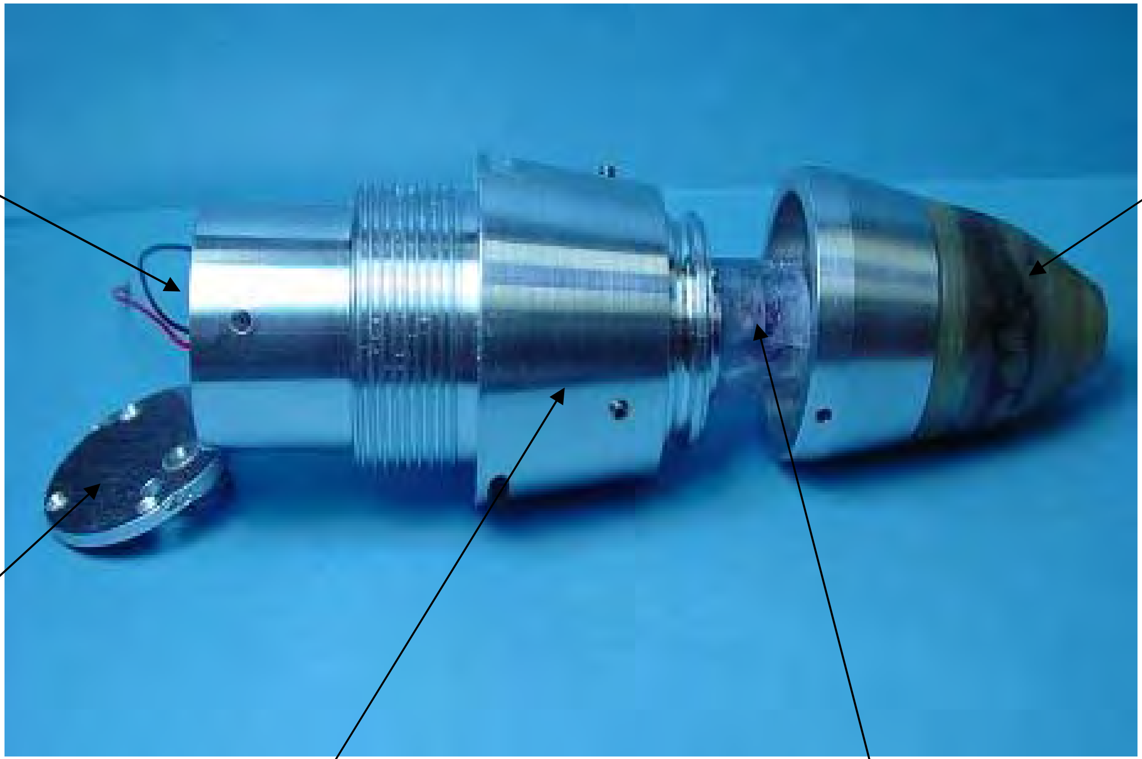


Zig-zag setback switch

High-G ESAD Hardware

Battery

Prox sensor



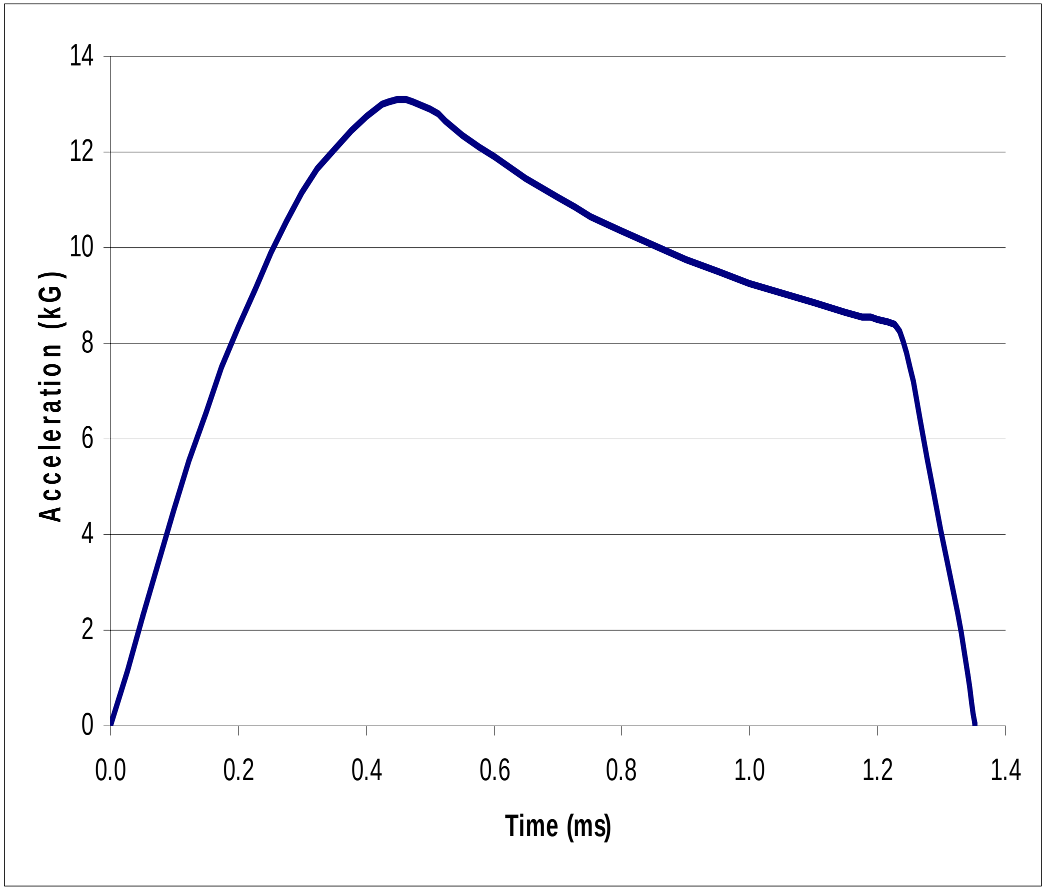
Base plate

Fuze body

Zig-zag switch holder

Air Gun Shock Pulse

All system components have been demonstrated to survive high-G air gun shock testing.



Current Status

- Initial design for mortar fuze application completed
- Fabricated 10 full-up assemblies.
- Explosive train reliability testing finished for fuze booster.
- Air gun shock testing completed on two units
- Ballistic test planned for remaining 8 units
  - 4 units with in house fireset
  - 4 units with Kansas City Plant fireset
- Awaiting field test Summer 2006

“Inadequacy of traditional test methods for detection of non-hermetic energetic components”

George R. Neff & Jimmie K. Neff
IsoVac Engineering, Inc., Glendale, CA

Barry T. Neyer
PerkinElmer Optoelectronics, Miamisburg, OH

Karl K. Rink
University of Idaho, Moscow, ID

The Authors Competency

- ***Many decades of experience in leak detection and failure analysis***
- ***Manufacture of ordnance devices***
- ***Fundamental research in ordnance device designs and performance***
- ***Academic research in leak testing theory and application***
- ***Preparation of Military Standards & Commercial Test Specifications***

The Hermeticity Test Problem

- Poor understanding of leak test theory
- Misapplication of test methodologies
- Failure to understand device geometry
- Committing to traditional practices
- Ignoring MIL-STD limitations
- Lack of Field Feedback
- Inferior failure analysis
- Weak Statistical recordkeeping

The Hermeticity Callouts

Most Ordnance Devices have “Seal-Test” callouts of:

Visible to 5 x 10-6 std cm^3/sec

(The “Gross-Leak Rate Range”)

Many Ordnance Devices have Small & Zero-Cavities that are:

0.01 cm^3 through 0.000001cm^3

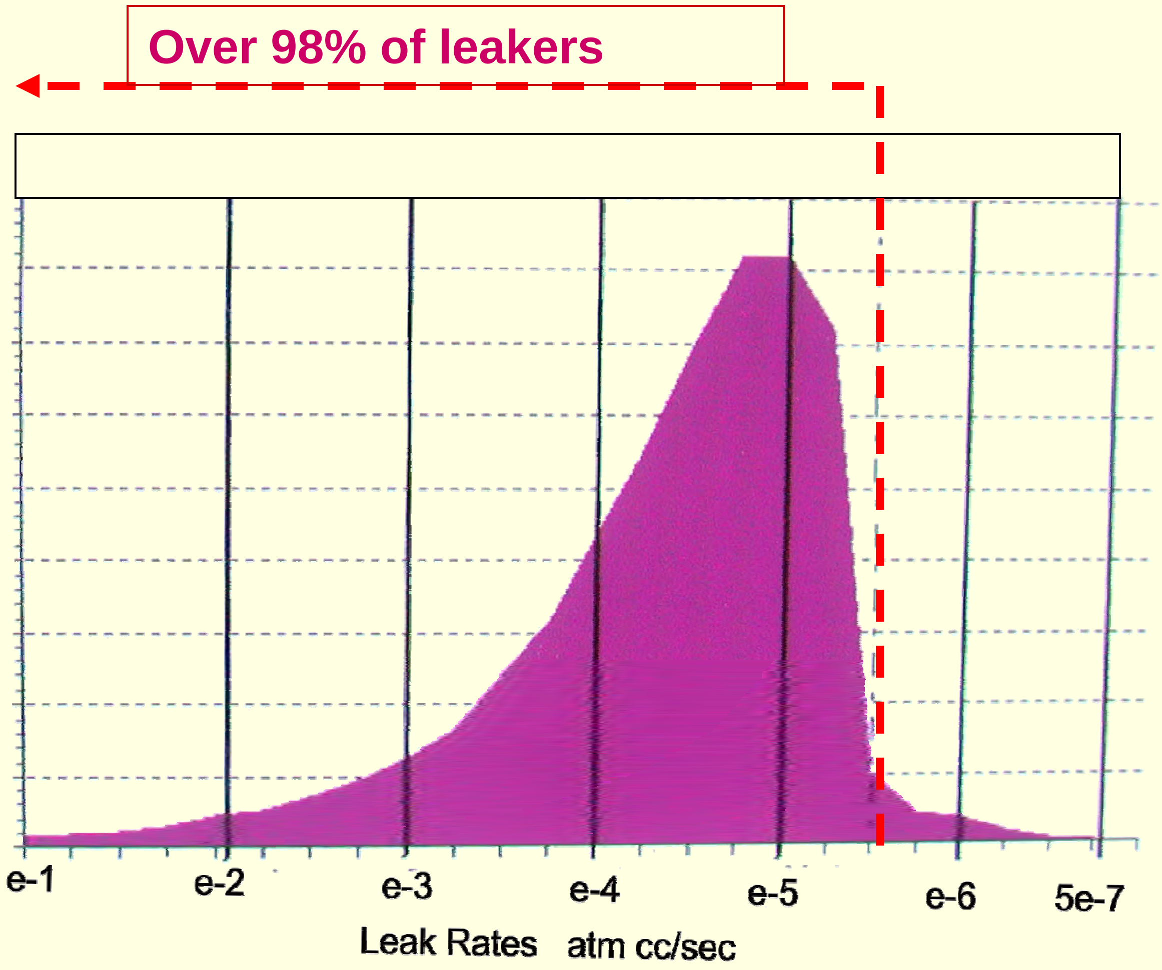
Test Methodology Reviewed

Helium Mass Spectrometry

Radioisotope Test Method

Red Dye Penetrant Failure Analysis

Typical Leak-Rate Distribution



Test Methods

Helium 'Mass-Spec' leak test method, (HMS)

- ***Being misapplied for "Gross-Leak" testing***
- ***Requires "Caution" with small ordnance devices***
- ***MIL-STDs limit HMS to Fine leak testing only, and not allowed for Gross leak testing.***
- ***Unreliable to detect "gross leaks" in "Small & Zero-Cavity" devices***

Helium Mass Spectrometry

<u>"Back-Pressurization"</u>

- Various bomb times and pressures
- Parts measured Individually
- Parts are evacuated prior to measurement
- Helium is lost during evacuation

<u>Tracer-Gas loss During Evacuation</u>:

0.0001cm^3 cavity with 10^{-4} std cc/s leak

- 99.99% of Helium tracer gas in 10 sec.

Helium Mass Spectrometry

***A "Leakage passage" Usually has short length and a 'passage' <u>volume</u>*: < 10^{-5} cm^3**

***<u>Therefore:</u>* With a 10^{-4} cm^3/s leak rate:**

"Helium is gone in <u>Less than 1 second".</u>

***<u>Then</u>:* Detectable helium is only from:**

"Interparticulate" cavities or "He Dissolved in Binders", very slowly released.

Result is an "Indicated-Leak" less than the spec, and an "escaped leaker".

Radioisotope (Kr85) leak testing

- Called out in MIL-STDs for Gross & Fine leak testing
- Testing small (0.02cm^3) to large cavities.
- Testing “Small” & “Zero-cavities” with charcoal gettering.

Radioisotope Test Method

"Back-Pressurization"

0.01% Kr85 tracer-gas mixture

Measured "In-Place" (In Device Cavity)

Detectability: ~ 10^{11} molecules Kr85

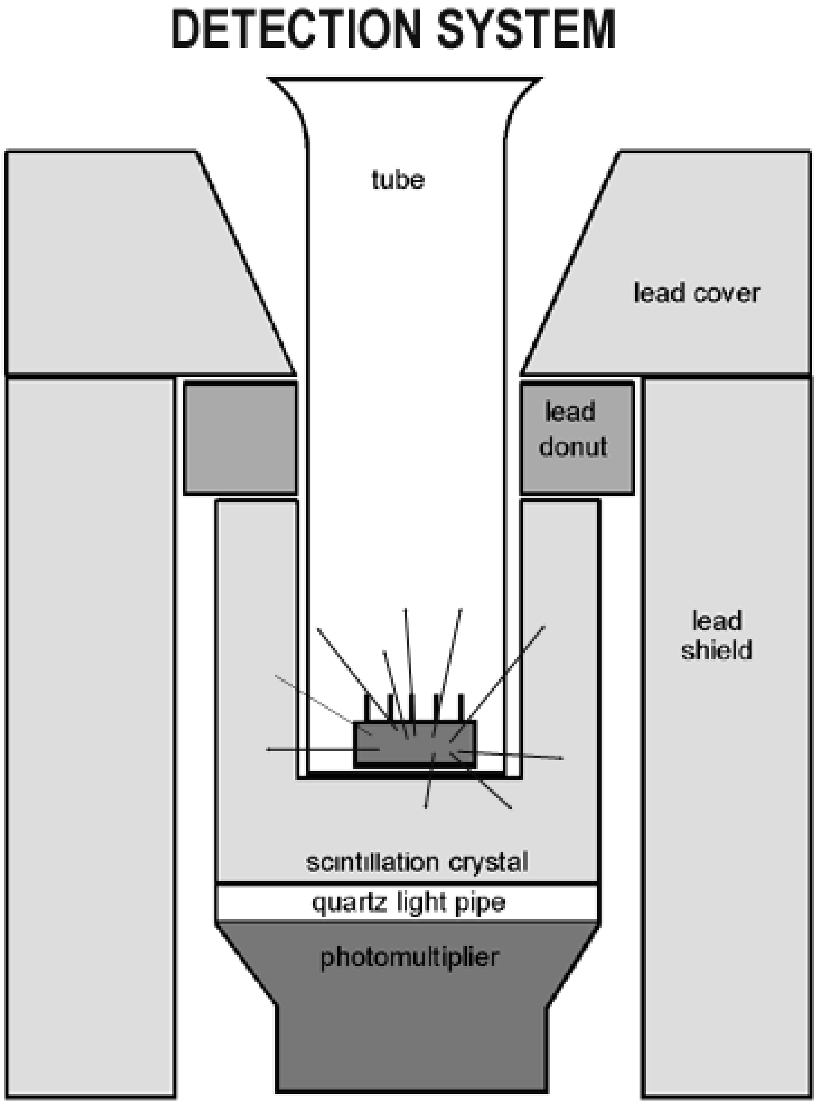
Bomb Times:

"Gross-Leaks" ~36 sec. (> 5 x 10-6)

"Fine-Leaks" ~6 min.

Technical theory of the test

- **The gamma rays from Kr85 gas trapped within a leaker, will penetrate the walls of normal devices, and are easily detected by the scintillation crystal at the counting stations.**



Dye Penetrant Failure Analysis

<u>Purpose”</u>

- **Verification of gross leakage**
- **Detectability to ~ 1 x 10^{-7} std cm^3/s**
- **Isolation of leak sites**
  - ***Glass header cracks***
  - ***Glass-to-metal seals***
  - ***Weld defects***
- ***Destructive test***

Vacuum Decay Equation

$$P_t = P_o\, e^{-kt}$$

<u>Where:</u>

P_t =Partial press Kr85 at time "t"

Po =Original partial press Kr85

$$k = \frac{\text{leak rate (std cm}^3\text{/s)}}{\text{cavity vol. cm}^3}$$

t = time in vacuum (sec)

The "Gettering" Technology

"Charcoal Gettering" of Kr85

1. ***Steam Activated Charcoal***
2. ***High surface area: 500m^2/gm***
3. ***Mixed with ordnance***
4. ***One Particle of Charcoal:***
   0.003" size, 0.243 µgm, vol. ~10^{-7} cm^3

<u>"Provides 133 mm^2 surface area".</u>

“Gettering” of Kr85

<u>“Steam-Activated Coconut-Shell Charcoal”</u>

1. **“Adsorbs” Kr85 tracer gas**
2. **Holds Kr85 by van der Waals forces**
3. **Does not effect ordnance materials**
4. **Adsorbs 27% by wt of water**
5. **Assures detection of ‘wide open leak’**
6. **Used in 50+ million Ordnance parts/year**

Leak Test Standards

MIL-STD-883

MIL-STD-750

MIL-STD-202

MIL-STD-S-19500

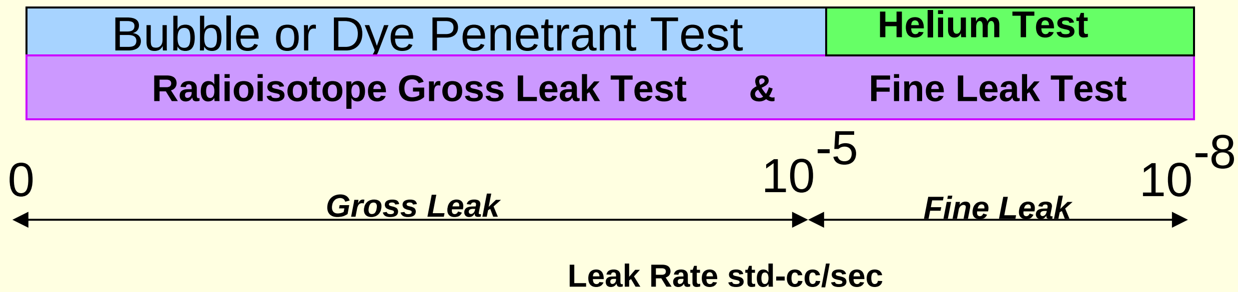
MIL-13474c-Squibs

S-113 Ordnance

+ Others, (Military & Company Specs)
Mostly: based on MIL-STD 202

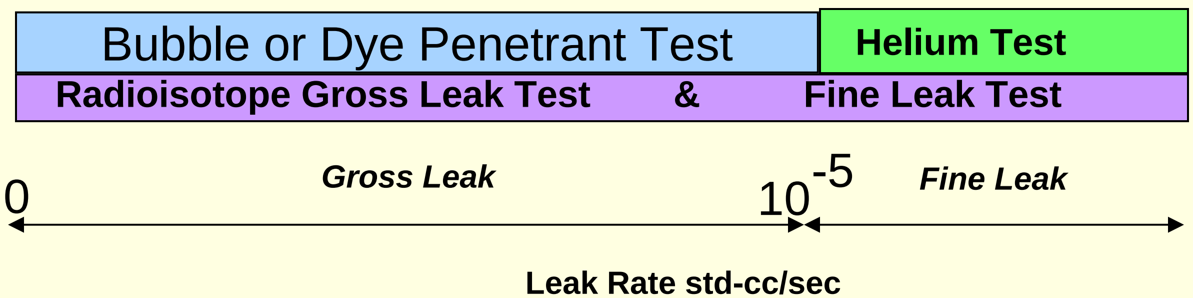
Leak Test Ranges for U.S. Specification Callouts

Mil Std. 883



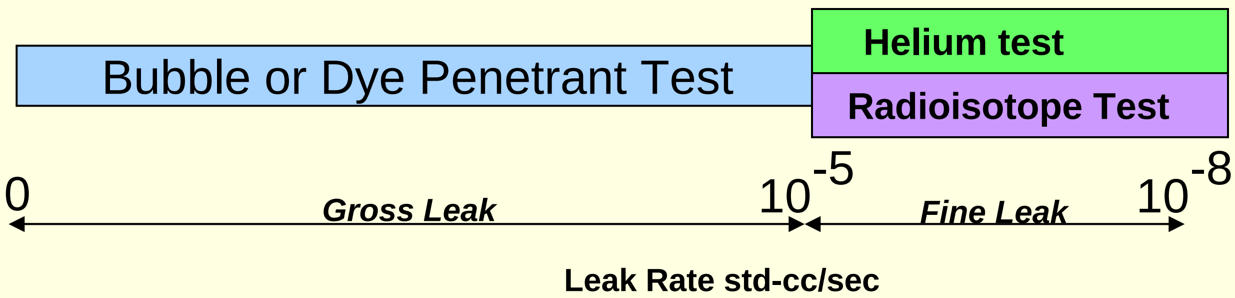
Leak Test Ranges for U.S. Specification Callouts

Mil Std. 750



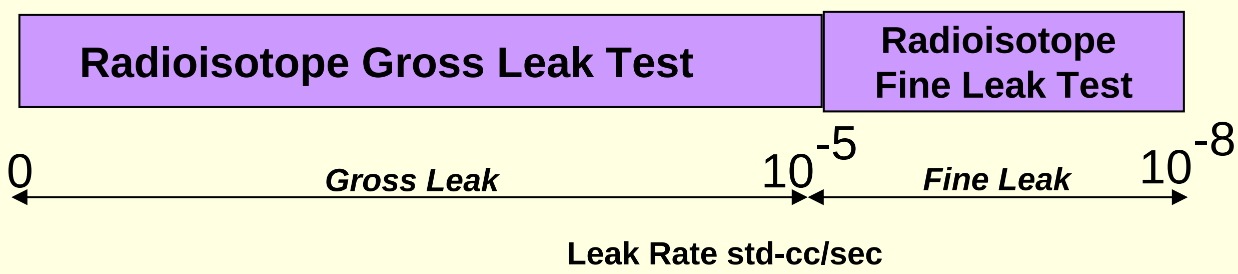
Leak Test Ranges for U.S. Specification Callouts

Mil Std. 202

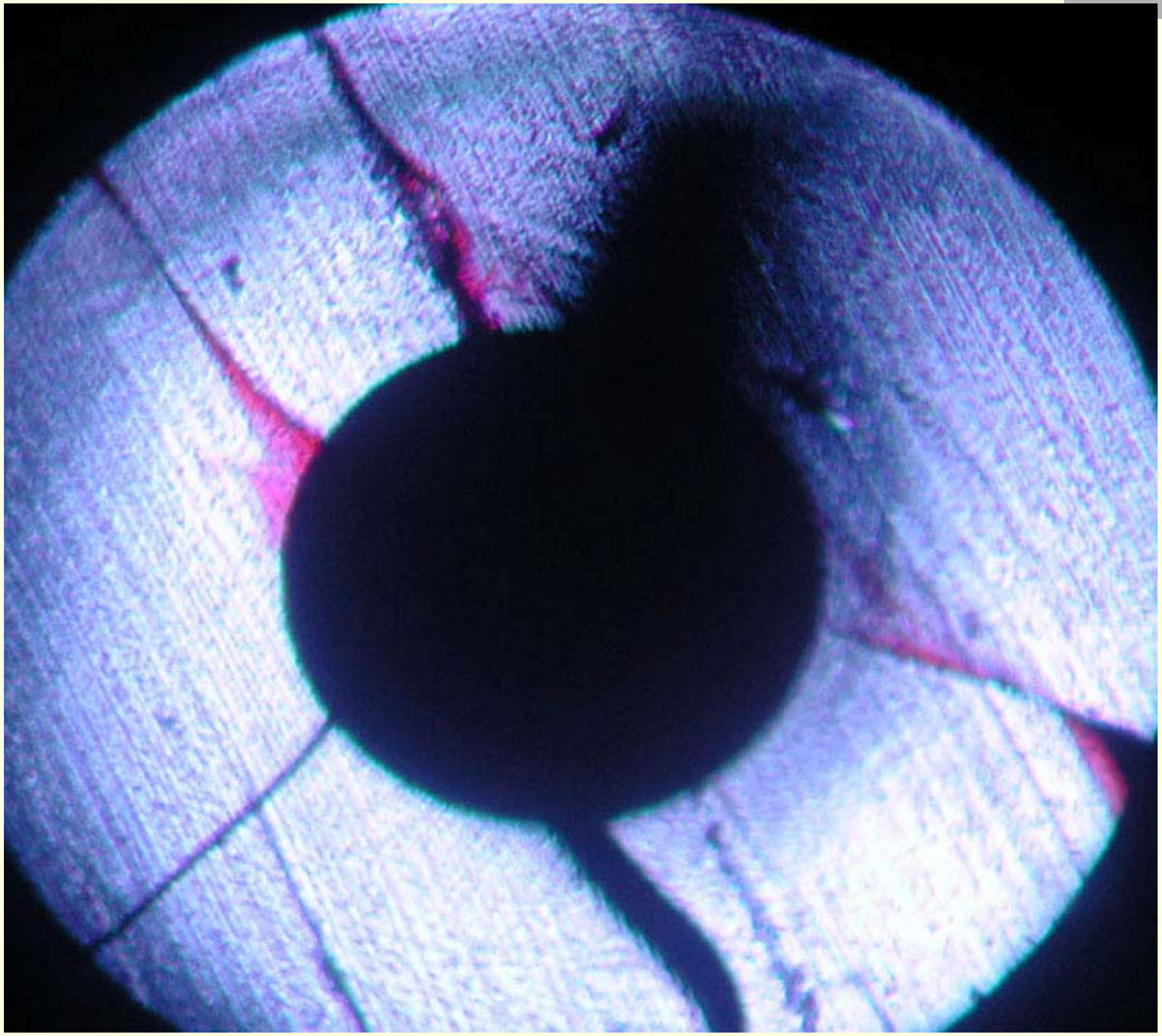


Leak Test Ranges for U.S. Specification Callouts

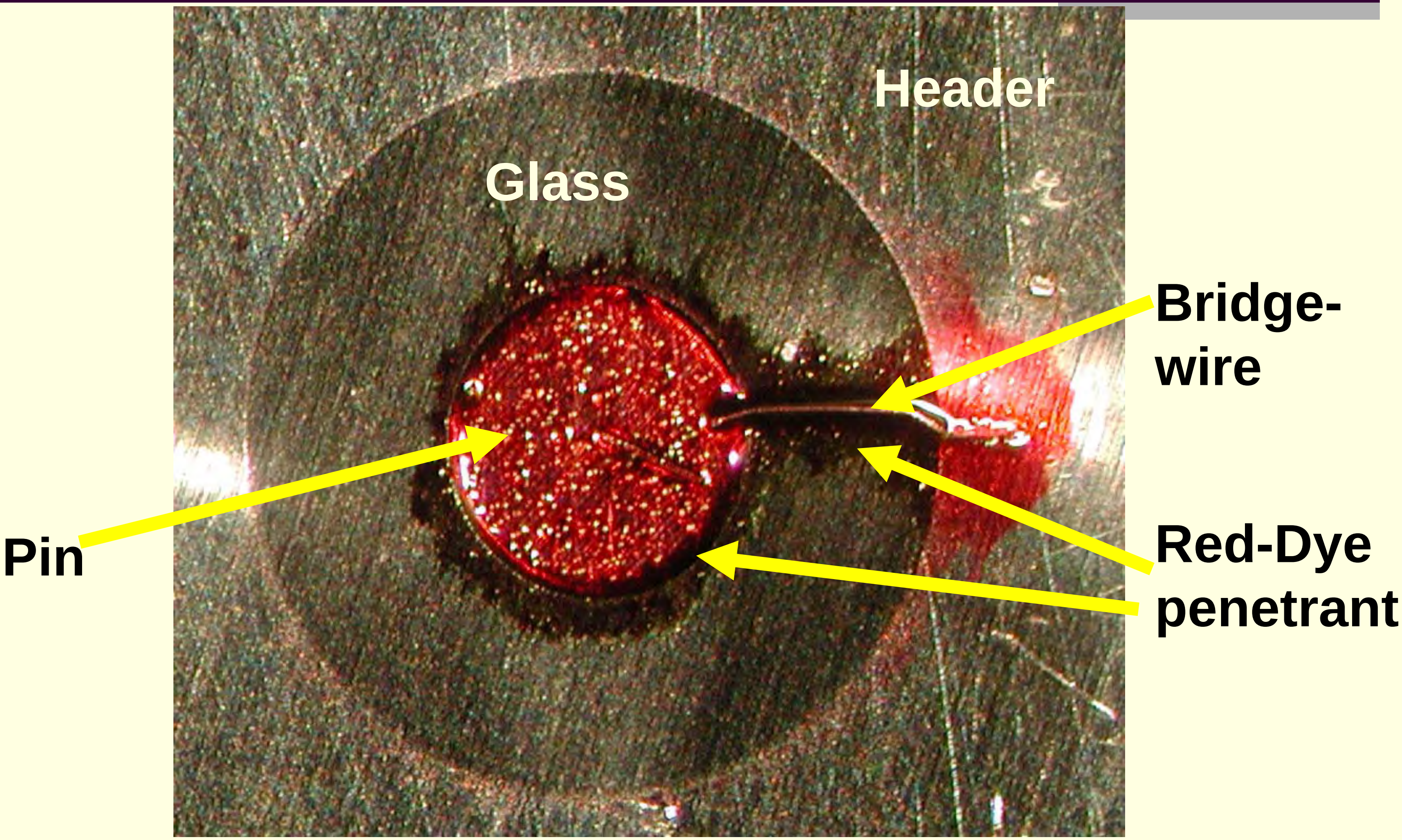
MIS-13474C (Missile Inspection Systems-Squibs)



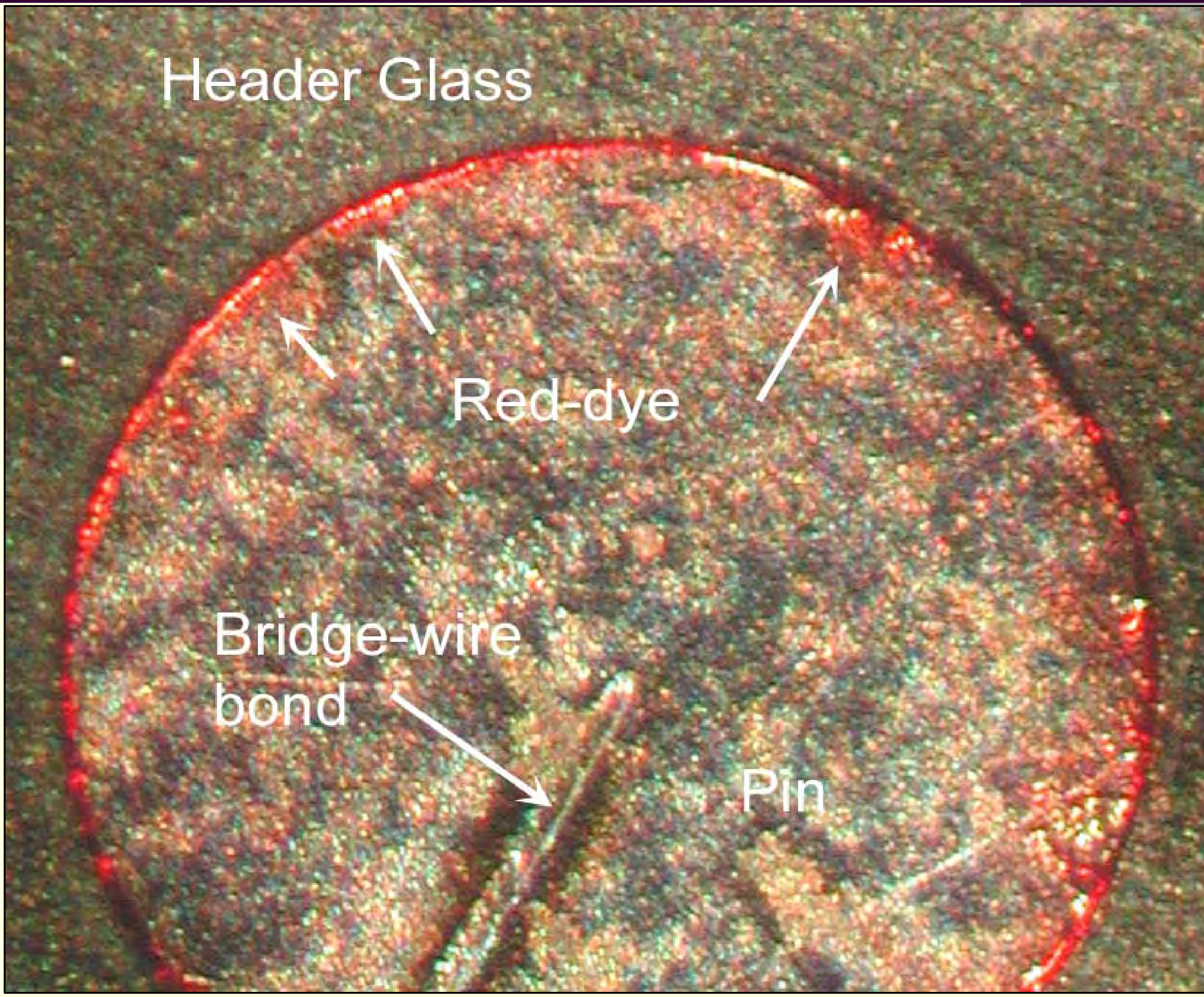
Red-Dye in "Header Gross-Leak"



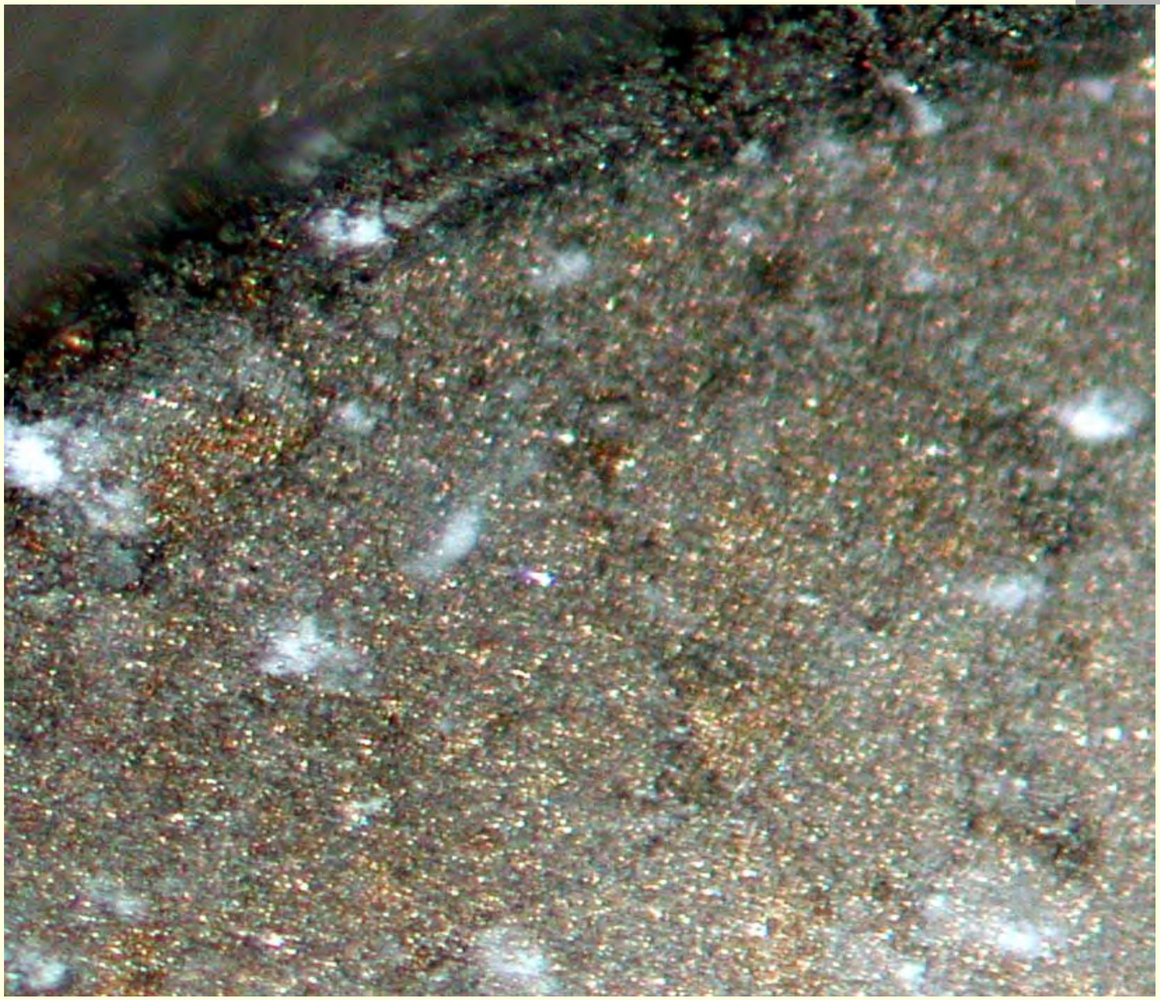
Pin-Glass “Gross-Leak”



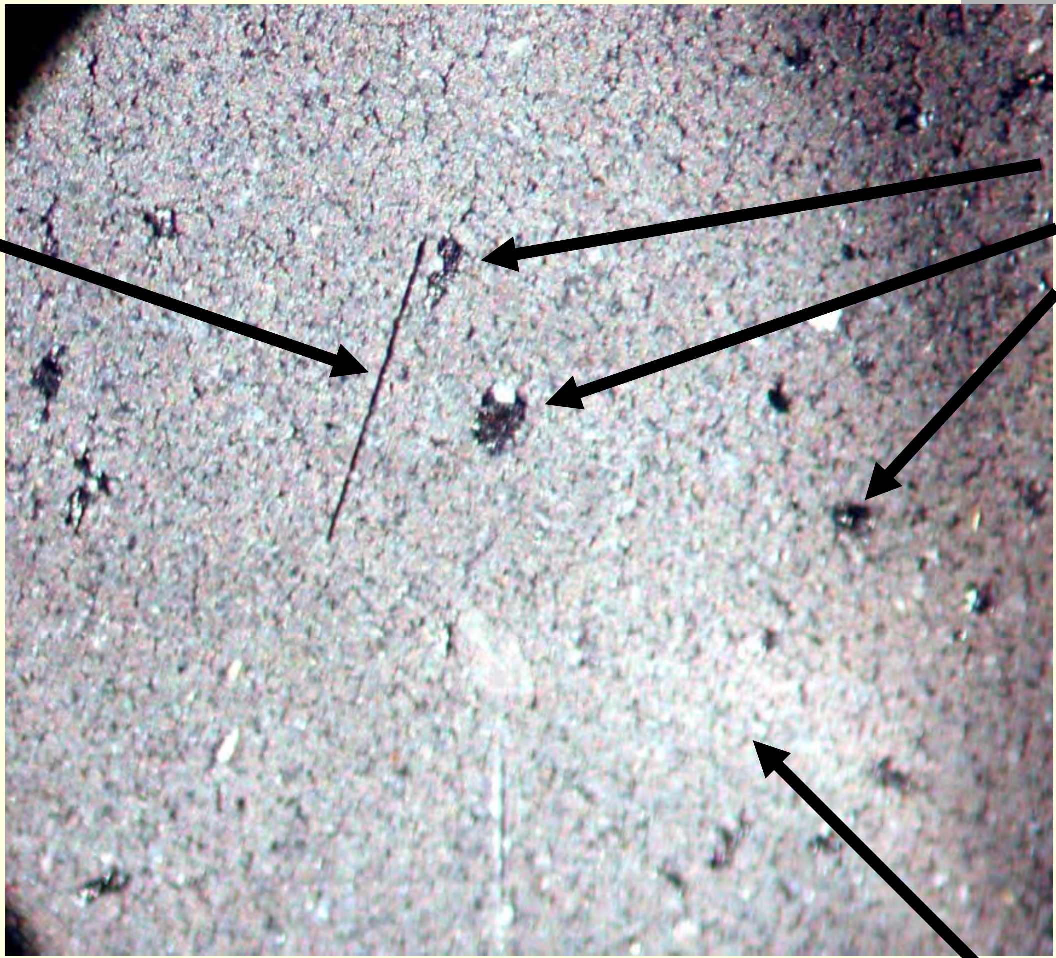
"Pin-Glass Gross-leaks"



“Fungus-Growth” on Ordnance

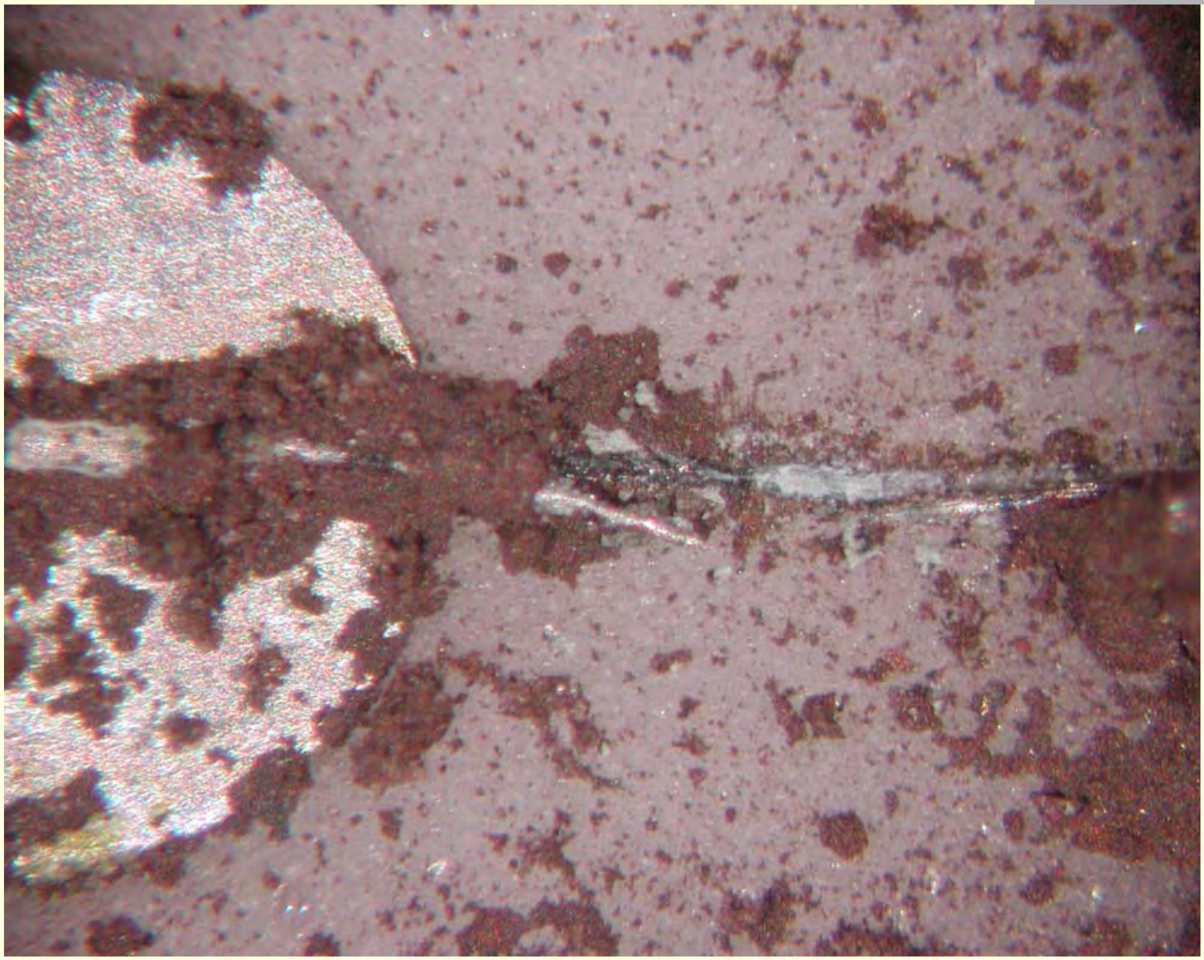


Charcoal mixed in ordnance



Impulse Cartridge

Residue of corroded bridge-wire



Need to Establish a Guaranteed Leak Test Method

- ***Leak testing*** of ***energetic products*** is ***inherently more complicated*** than a simple vacuum decay equation implies
- Need to ***research known leakers*** with proposed approach to ensure that the method works.
  - Investigate devices with known leaks in ***glass-to-metal seals*** and ***defective welds.***
  - Verify that the method can detect such leaks

Use of Academia

University of Idaho has developed some
<u>Unique Engineering Capabilities</u>

<u>Fully equipped for "Fundamental Research"</u>

- ***Skilled in Ordnance technologies***
- ***Sophisticated Ballistic testing***
- ***All leak testing methodologies***
- ***Hermetic seal mechanics studies***
- ***Gas and Moisture transfer through leaks***
- ***Ordnance material behavior***

The authors
Thank You for Your Time

May we answer any Questions?

THALES NDIA Briefing

Hard Target Reliability for MAFIS

L.J.Turner CEng MIMechE.

Ordnance Fuzing Group Manager

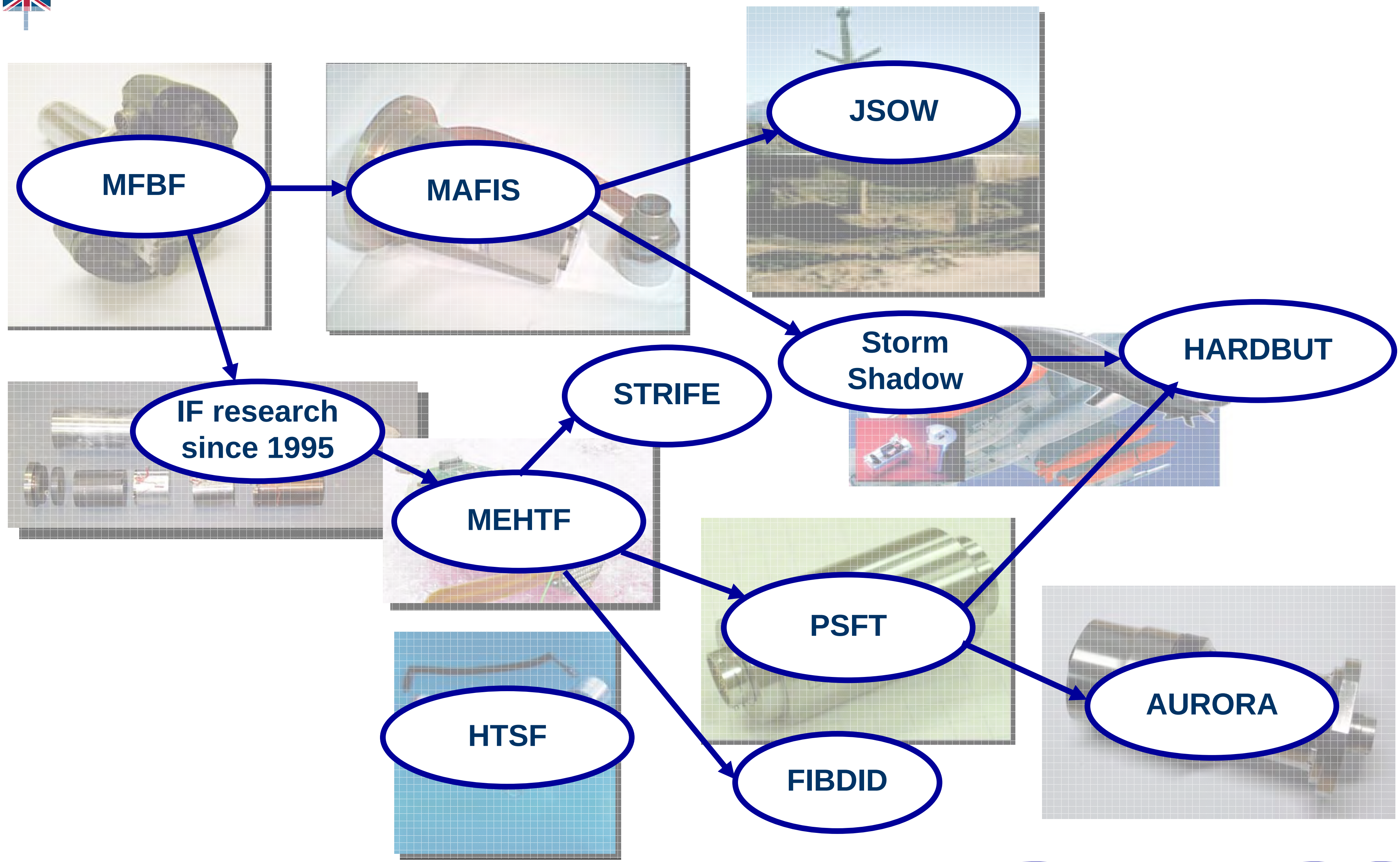
Company Background in Fuzing & Shock Hardening

1918	-	Shell Fuzing
1940s	-	Airborne Radar, Shell Fuzing, Proximity Fuzing (Rockets) Bomb Fuze for “Bouncing Bomb” etc.
1950s	-	Naval Proximity Shell Fuzing
1960s	-	No.907 RF Proximity Fuze for Bombs.
1970s	-	No.952 RF Proximity Fuze for Bombs. Multi Role Shell Fuze (MRF)
1980s	-	SG357 Runway Cratering Weapon MFBF (No.960) Multi-Function Bomb Fuze
1990s	-	Intelligent Hard Target Fuzing Research
2000s	-	Intelligent Hard Target Fuzing Production and Research, MAFIS, HTSF & AURORA.




Pioneer in hardened fuze electronics

TME Fuzing Family Tree



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TME Hard Target Fuzing

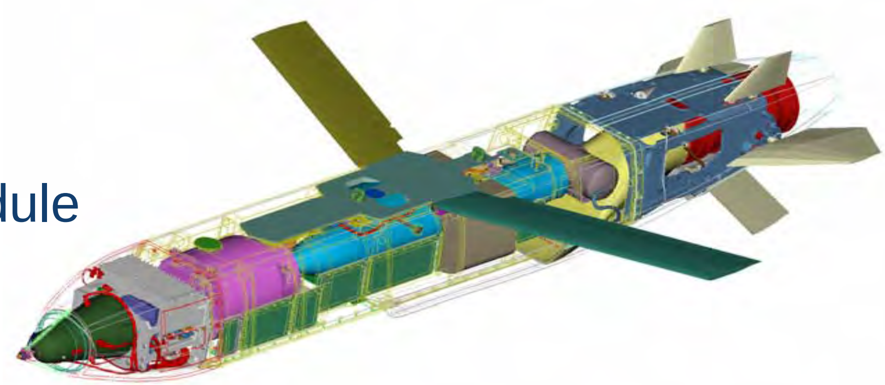
MFBF

AURORA
for
PGB (Paveway IV)

MEHTF & PSFT

MAFIS for
Storm Shadow & JSOW

MAFIS (Multi Application Fuze Initiation System)



Modular 3" fuze

- Shock hardened core electronics
- Application specific interface module

High shock survivable for MWS

Out-of-Line arming system

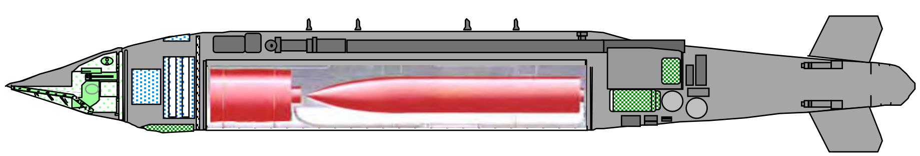
Missile fuze (including reliability requirements)

Initially developed for Storm Shadow with BROACH warhead

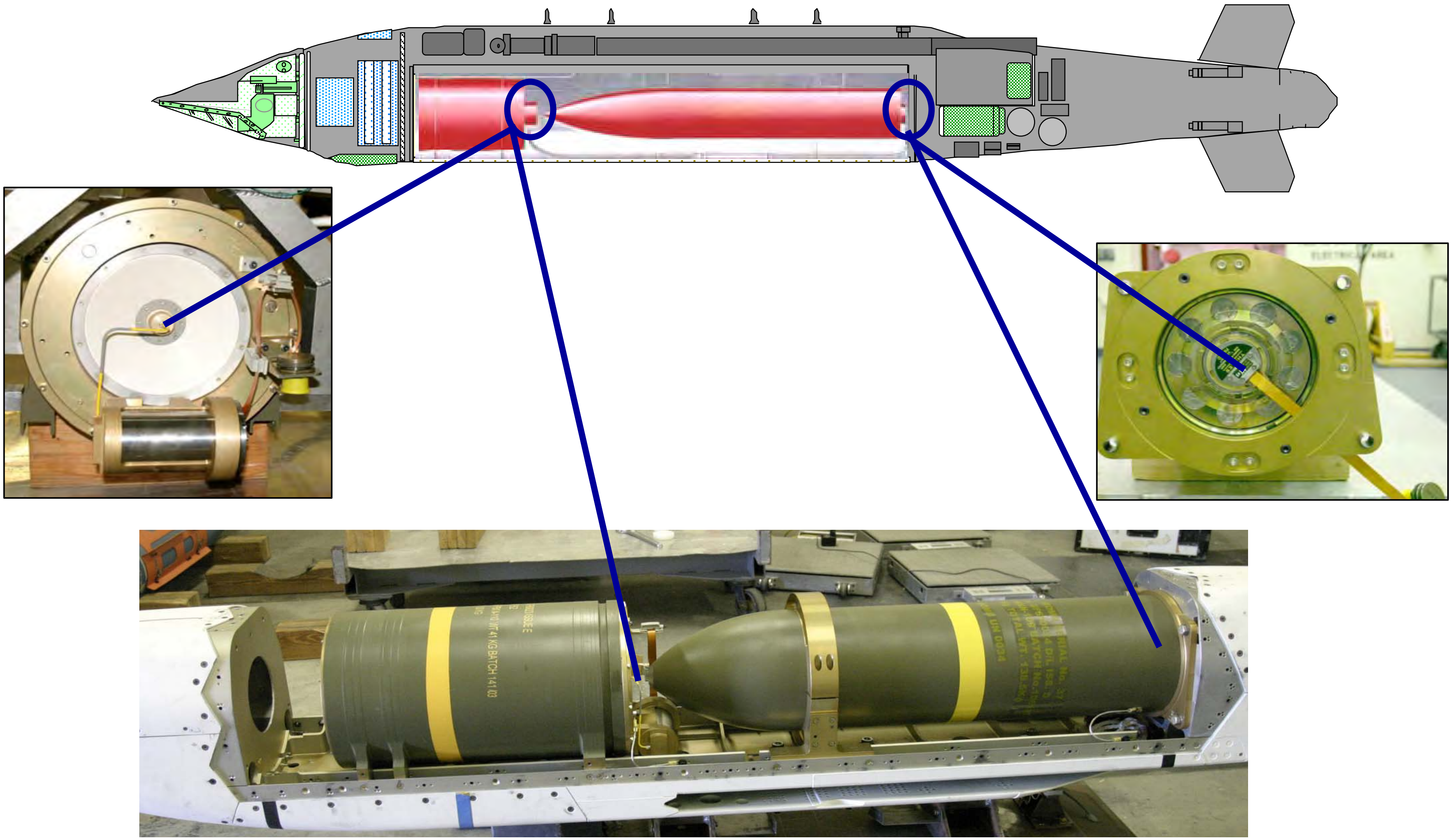
Modularity permits ready adaptation to other applications

In full production for:

- Raytheon AGM-154C (JSOW)
- MBDA Storm Shadow

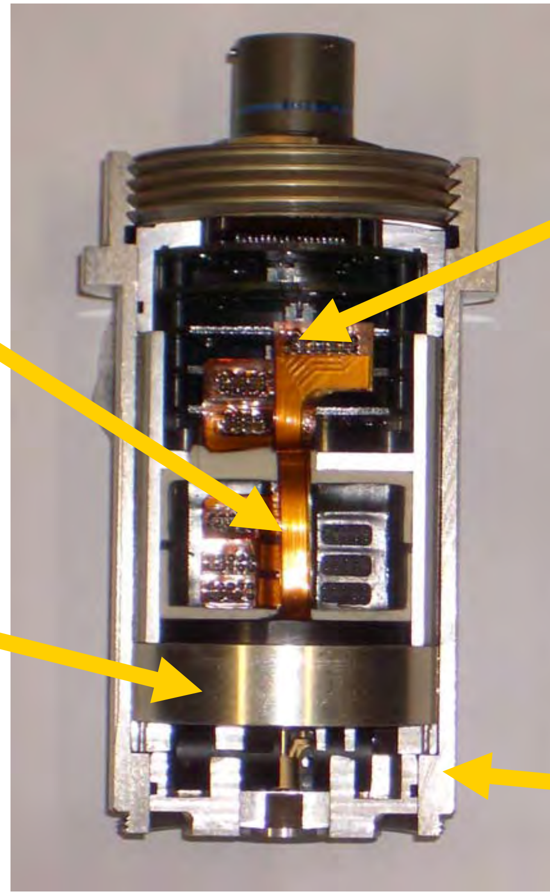


MAFIS (FSU-26/B) in JSOW (AGM-154C)



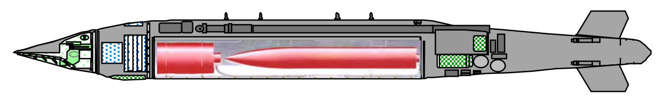
Core Electronics Module (CEM)

Application Specific Interface Module (ASIM)



Detonator Alignment and Safety Module (DASM)

Housing



Reliability in High “g” Domain

- Hard Target Fuzing
- Severe Environment for survivable electro-mechanics
- Multiple shock effects
  - High “g” levels
  - Multiple Impulses
  - Weapon Attack Angles & Angle of attack
    - **Fuze x 3 Axis – Longitudinal and Lateral**
  - Frequency range
    - **Excitation levels within fuze**
  - All over Temperature Extremes
- Real impact data difficult to collect
- Even more difficult to replicate for test

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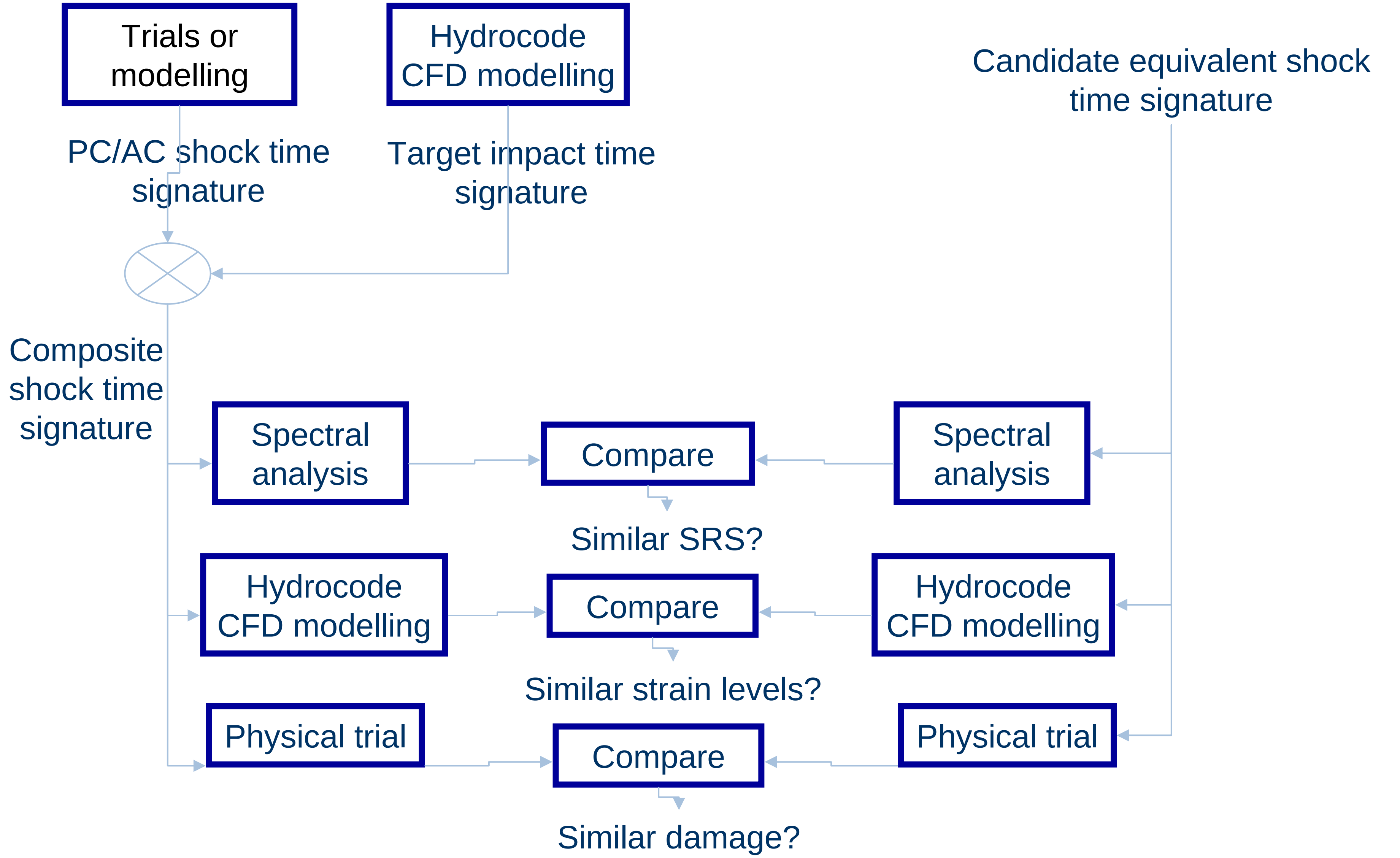
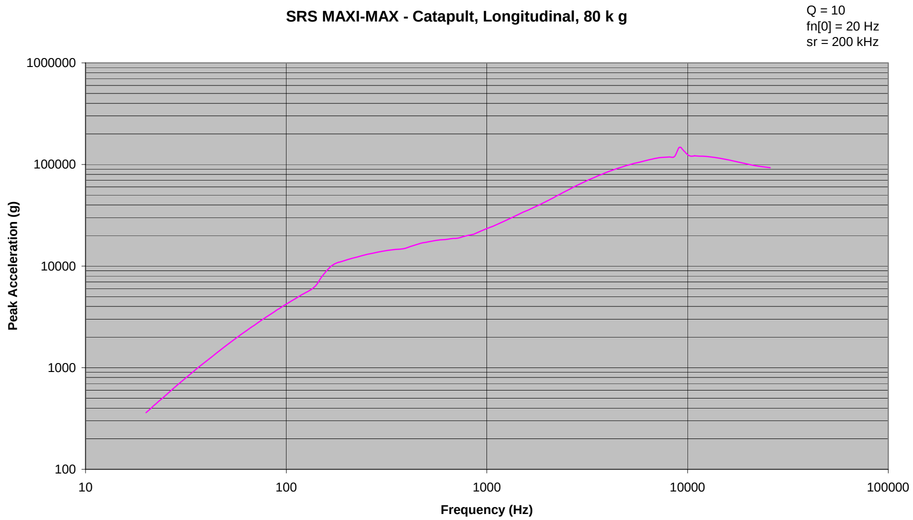

Trials or modelling
Hydrocode CFD modelling
Candidate equivalent shock time signature
PC/AC shock time signature
Target impact time signature
Composite shock time signature
Spectral analysis
Compare
Spectral analysis
Similar SRS?
Hydrocode CFD modelling
Compare
Hydrocode CFD modelling
Similar strain levels?
Physical trial
Compare
Physical trial
Similar damage?

	Computational Fluid Dynamics Simulation	Sled Trials	Catapult Trials
			
Advantages	•Inexpensive •Repeatable •Rapid	•All up round physical test •Closely replicate the tactical environment	•Inexpensive •Repeatable •Rapid •Adjustable shock environment •Temperature Extremes
Disadvantages	•Difficult to Validate •Easy to misinterpret the results	•Expensive •Non-Repeatable •Infrequent •Ambient Temp	•Requires Validation

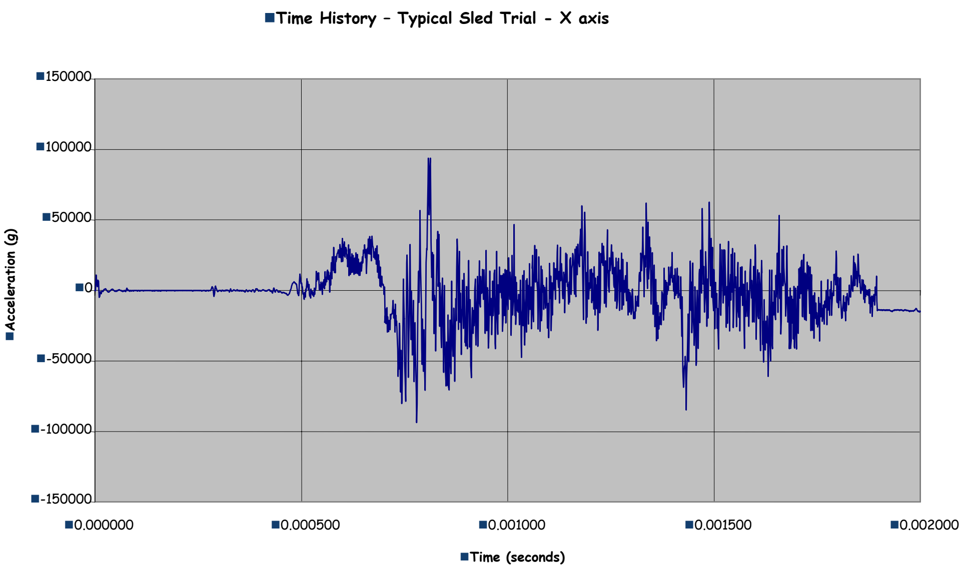
Basis for SRS Analysis and Test

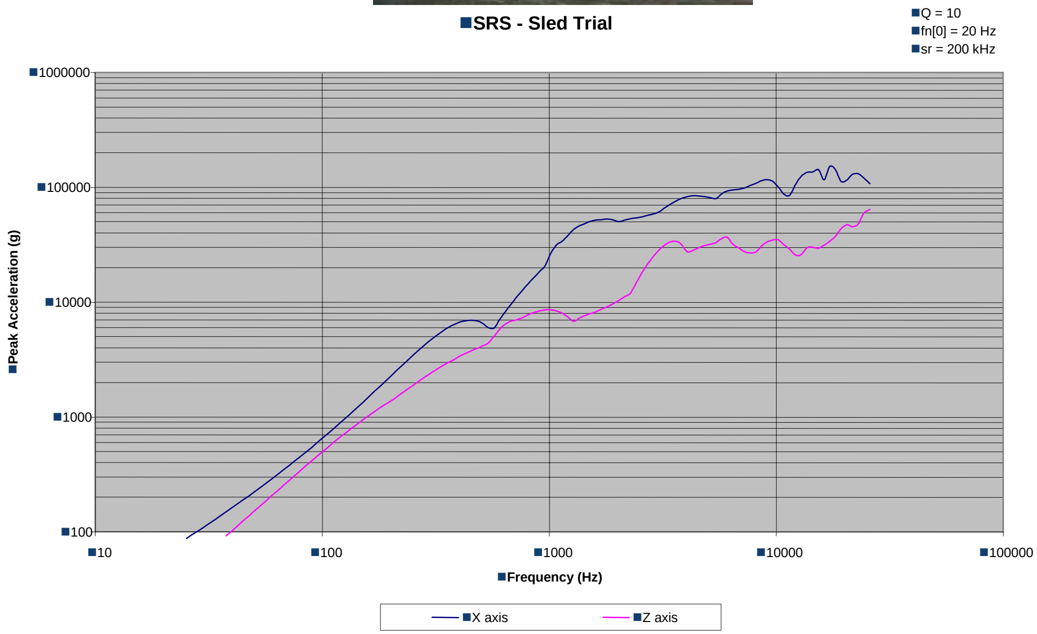
- Shock Response Spectrum

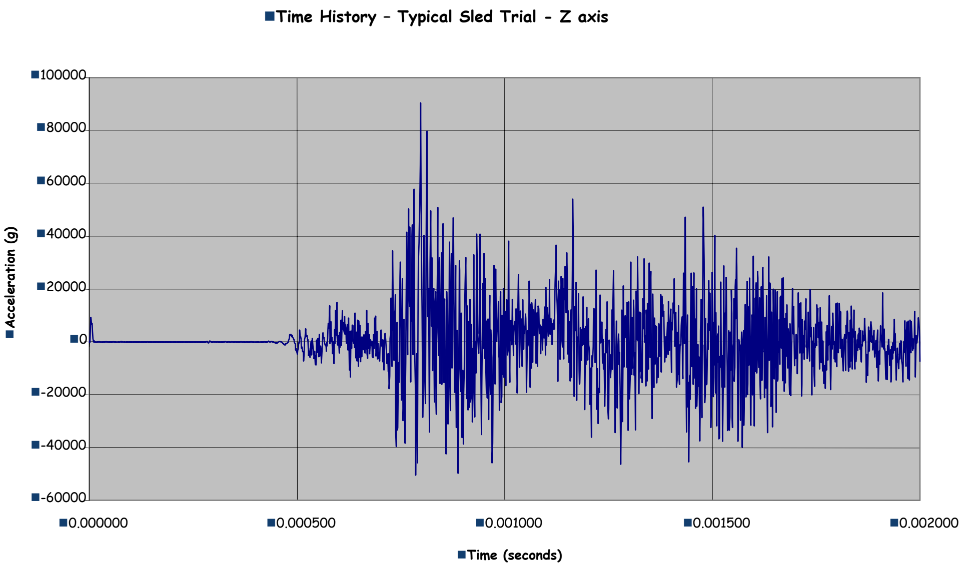


- Applicable for material transient responses with complicated waveforms
- Enables the tailoring of shock exitations from actual data for the operational environment
- Proven technique for shock simulation testing of complex waveforms
- Identified in UK (DEF STAN 00-35) and US standards (MIL-STD-810)
- Purpose of test to demonstrate the adequacy of material to resist degradation of functional / structural performance

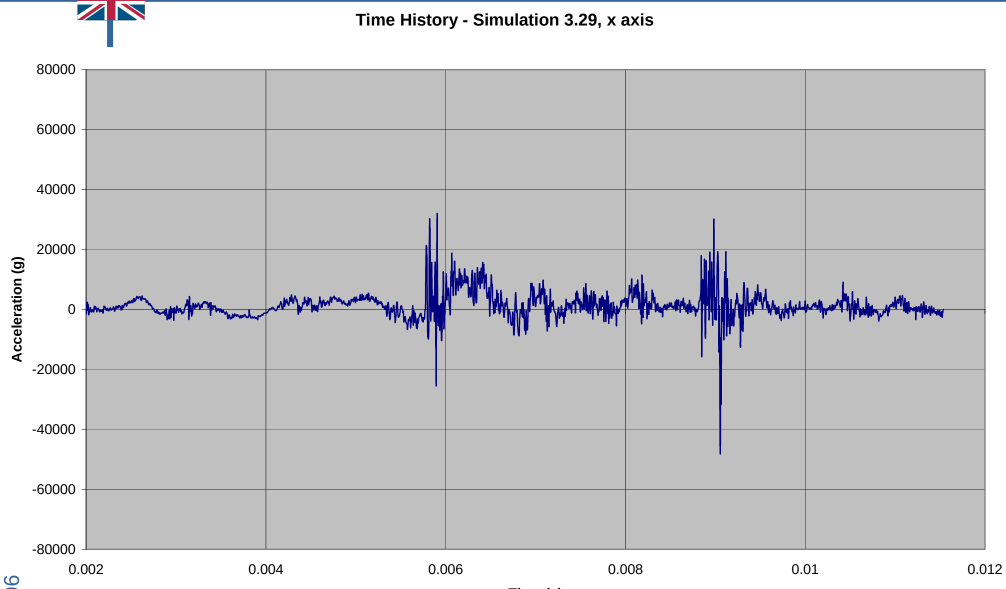
Typical Sled Trial Signatures

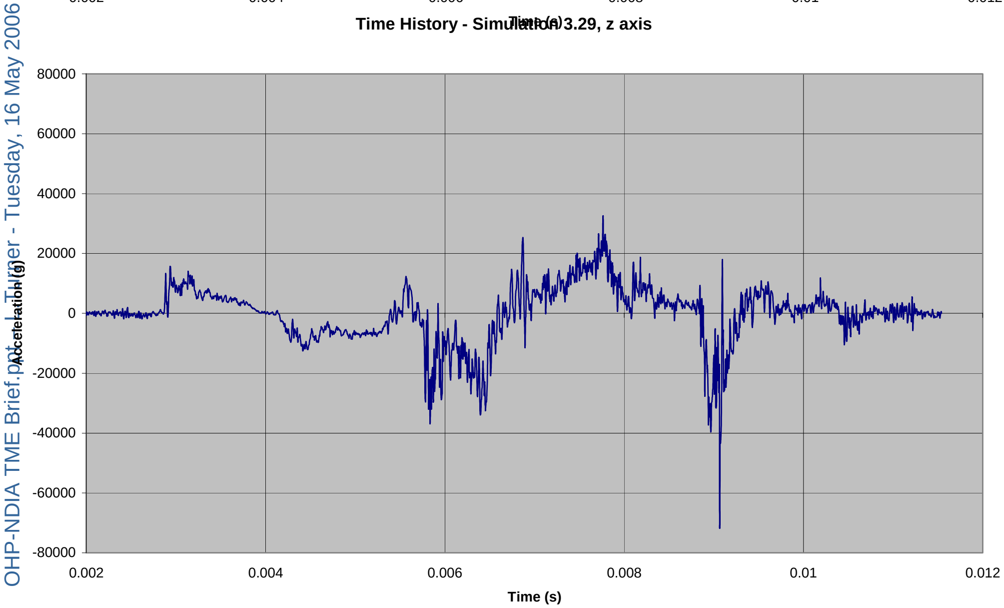


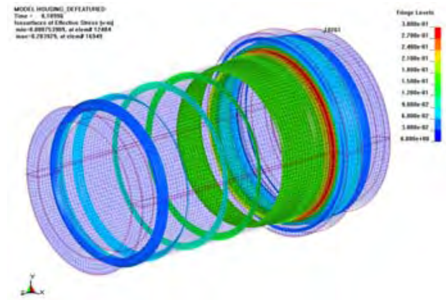


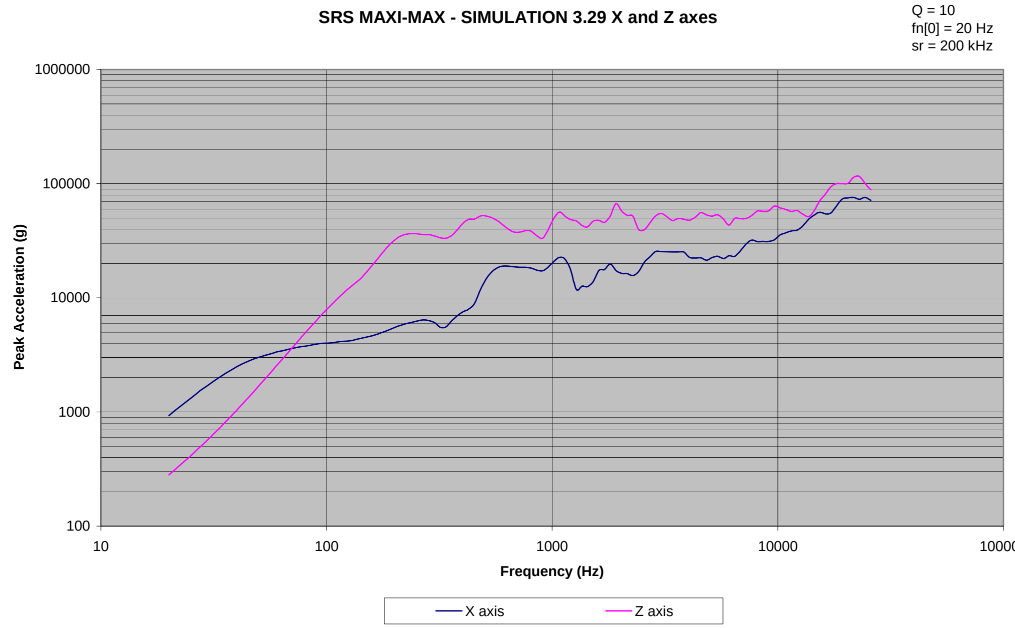


Typical CFD Simulations









CFD Model construction can affect simulation

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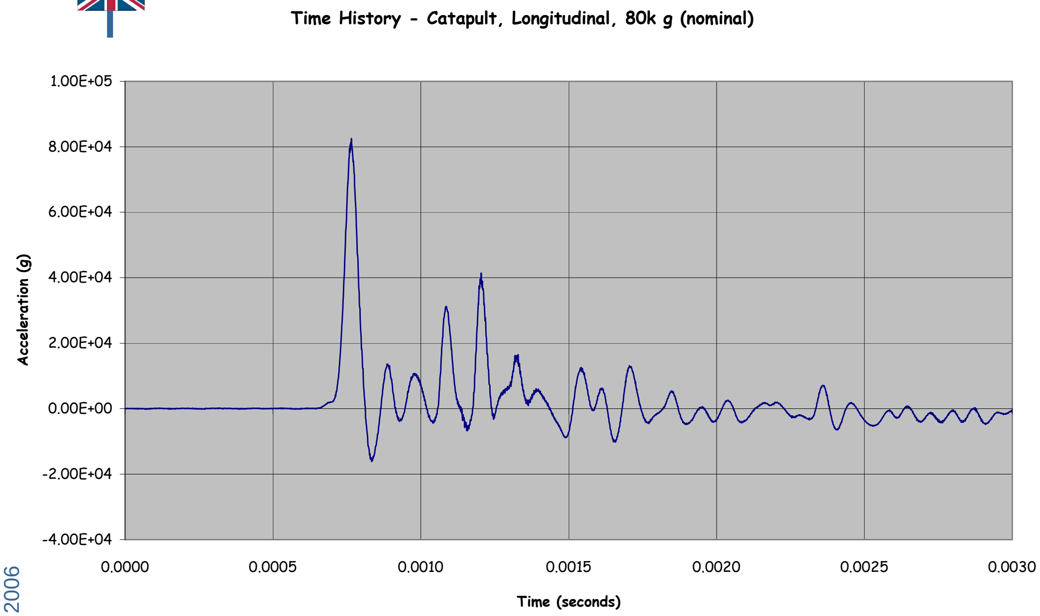
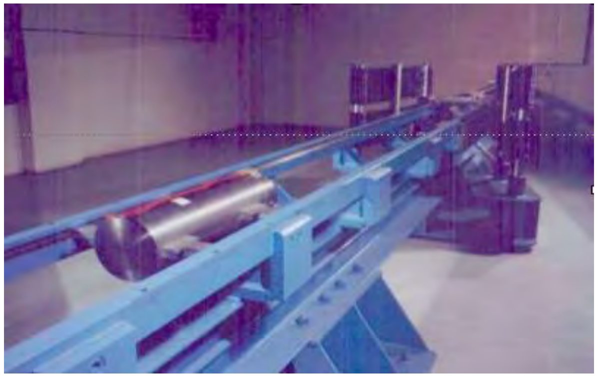
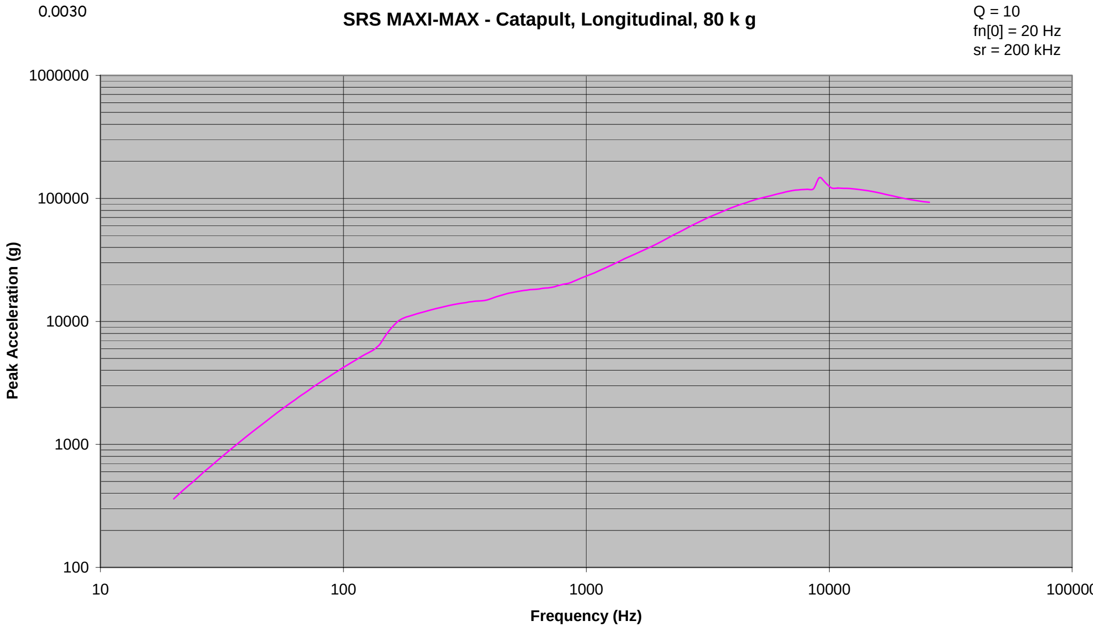
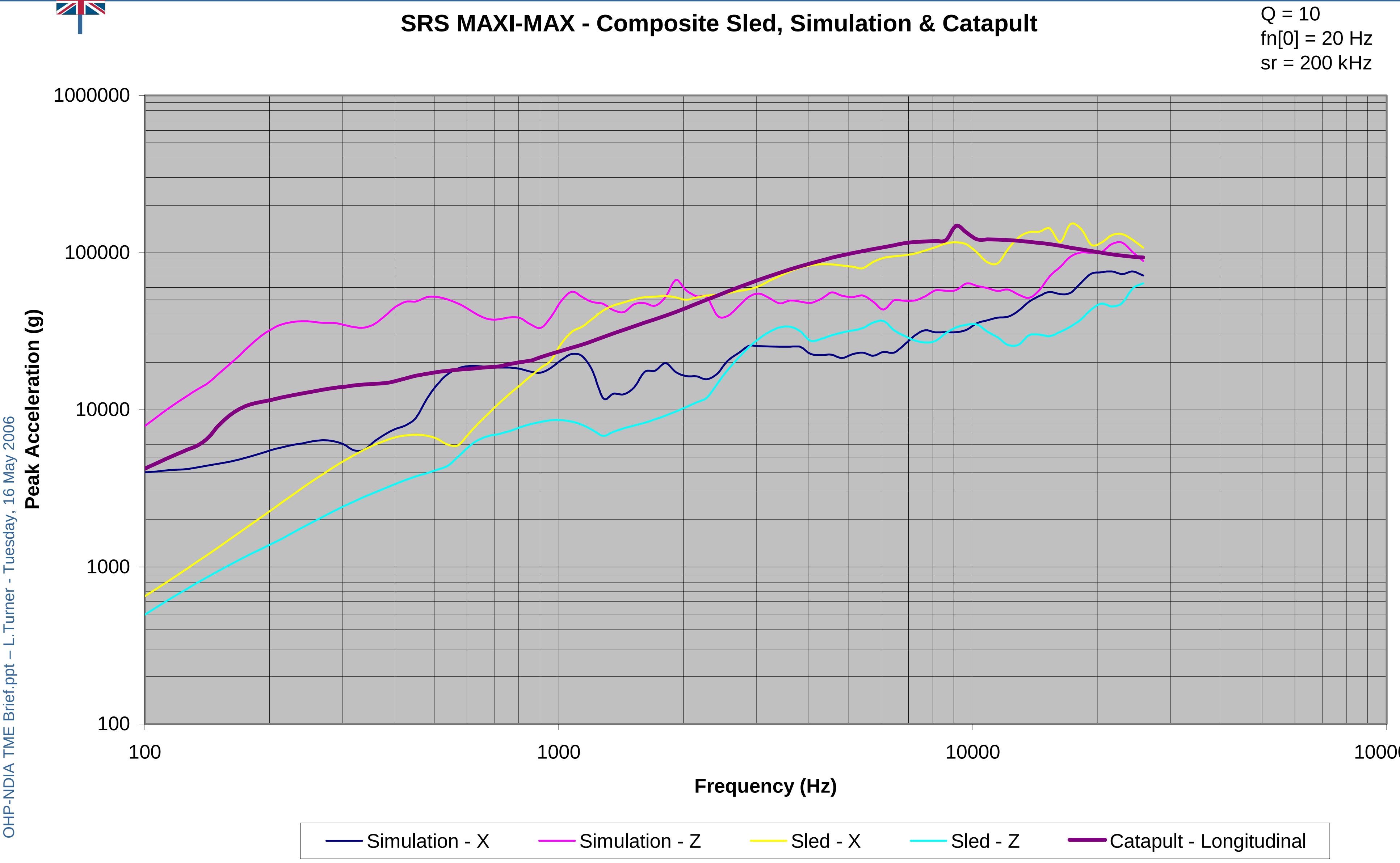
Typical Catapult Trials Data

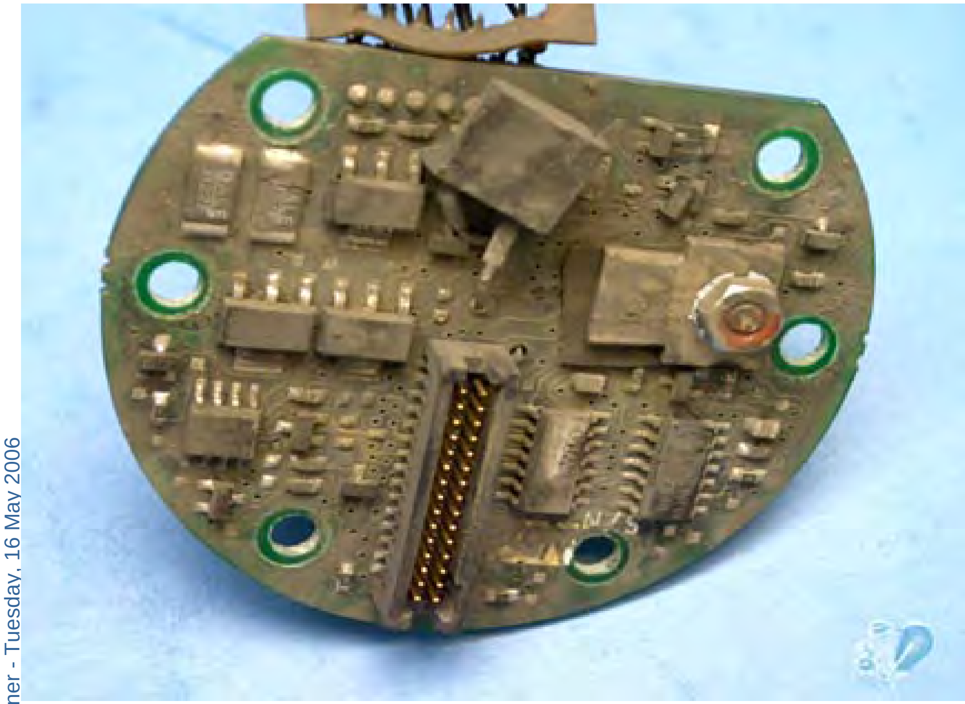




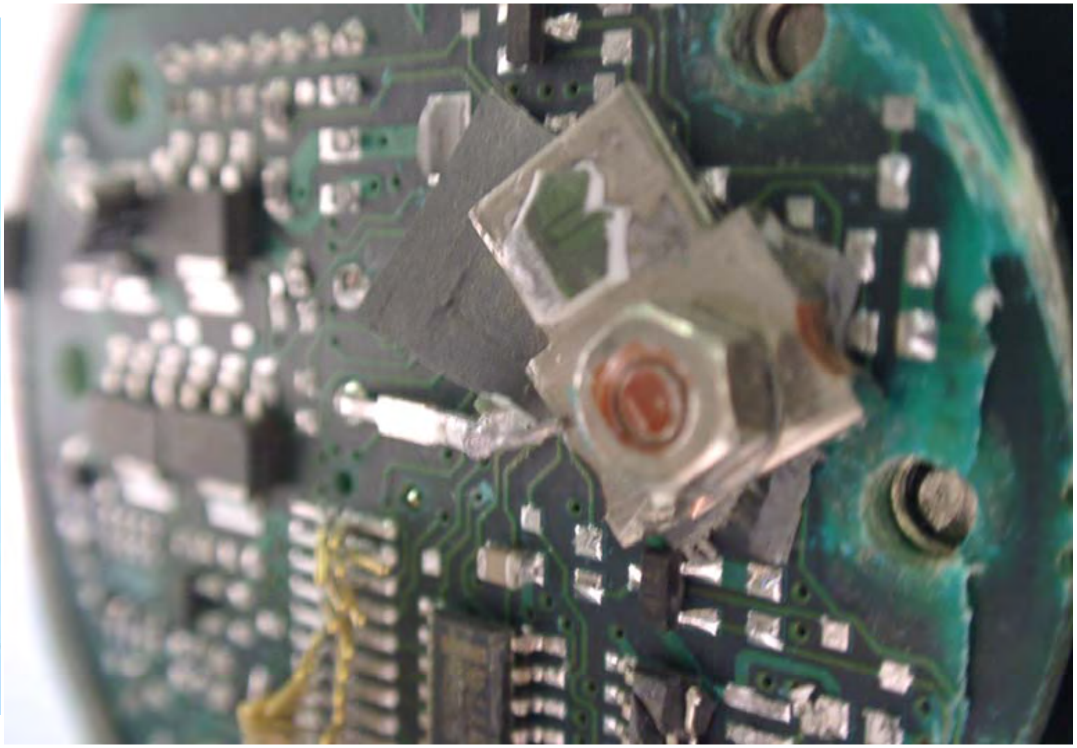


Sled / CFD / Catapult Comparison



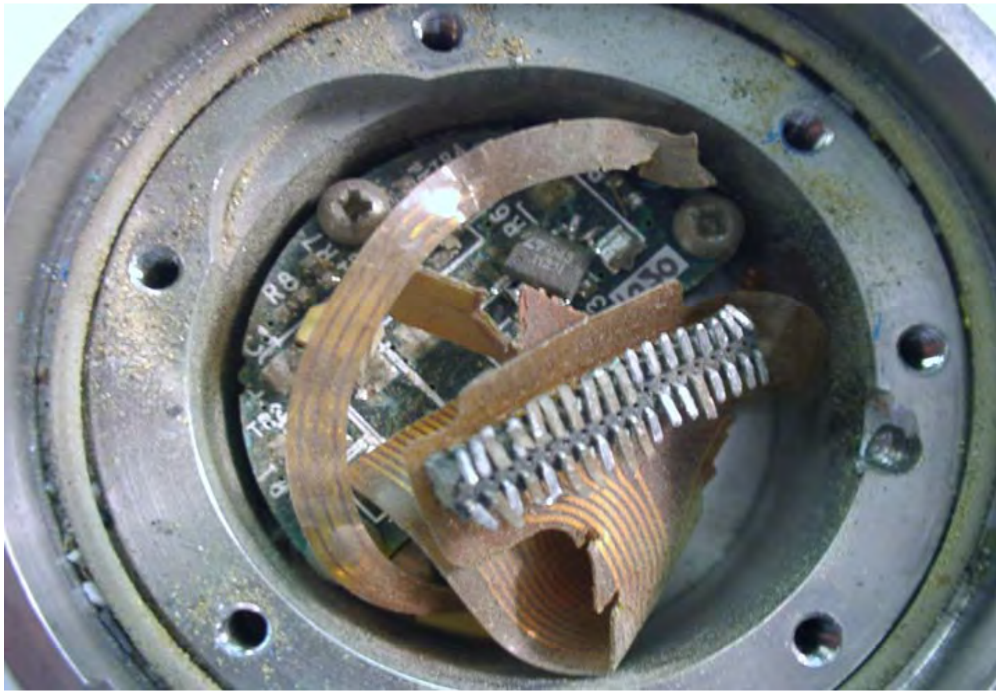


Sled Trial Damage



Catapult Test Damage

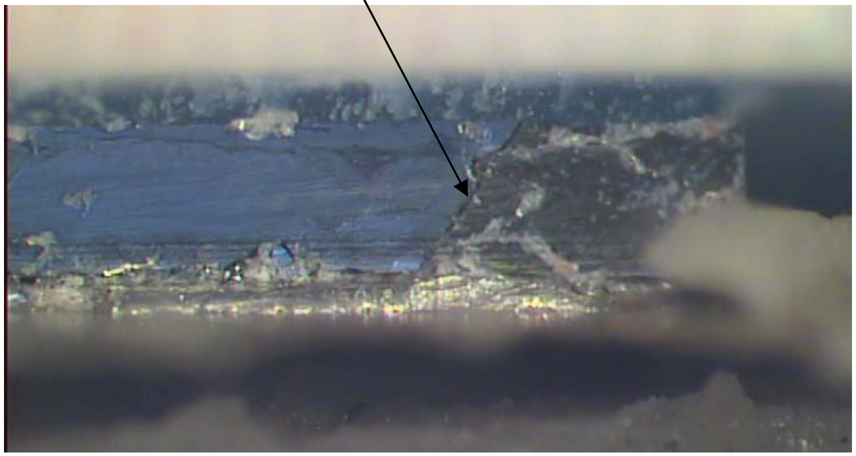
Sled Trial Damage



Catapult Test Damage

Damage to silicon component die

Fracture



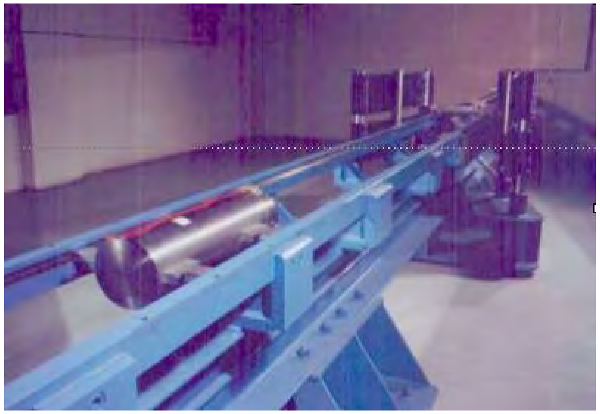
Fracture

Sled Trial Damage

Catapult Test Damage

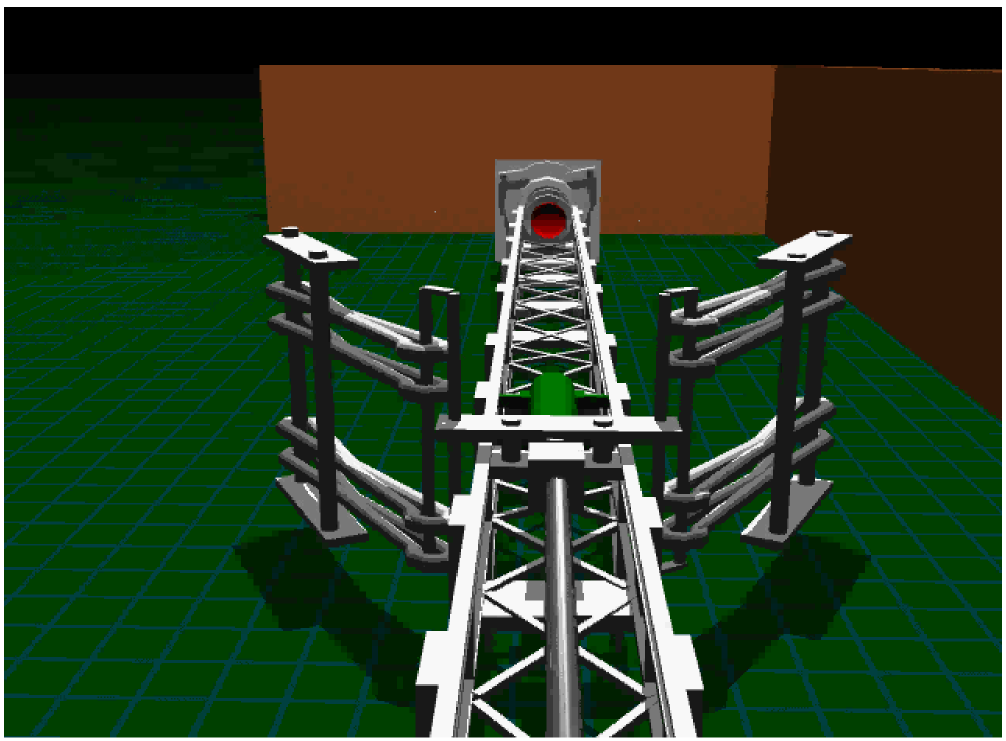
- Selected for capability to generate comparable SRS levels
- Creates ‘equivalent damage’
- Quick testing turnaround
- Multiple Test configurations
- Longitudinal
  - Predominately axial shock application – Multiple impacts
  - Variable shock parameters – “g” x Duration
  - Selectable Fuze roll orientation
  - Temperature extremes
- Lateral
  - As above plus simultaneous lateral and axial shock application – Multiple impacts

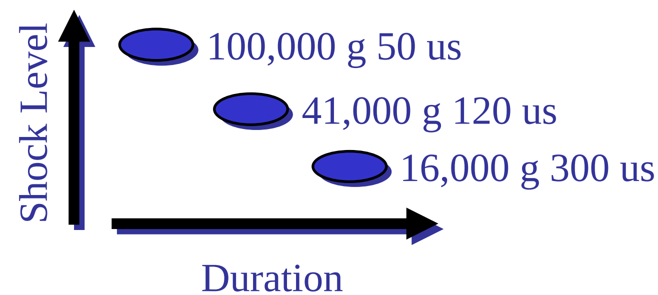
Testing for Survival and Function – Catapult

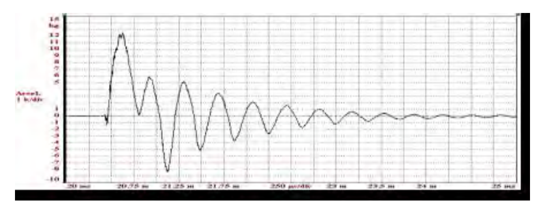


Test vehicle:

- Mass: 22 kg max
- Velocity: 50 m/s max
- Shock: 100,000 g







Typical shock signature

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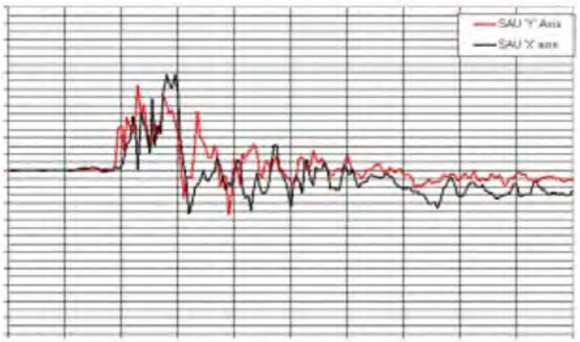
- Shock counter shock (SCS) facility
  - High speed impacts
  - Multiple shocks
    - (typically +50kg for 700μs, -20kg for 600 μs)
  - High off-axis angles (Sub Modules)



Off axis test vehicle

Shock-Counter-Shock High Impact gun tests

- MAFIS Hard Target Fuze
- Successfully tested in excess of 50 K"g"
  - Multiple effects, 3 Axis, temperature extremes etc.
  - High reliability – Missile levels
- In full scale production
- In service with RAF and USN
  - Storm Shadow & JSOW
- Growth path
  - Void & Layer insertion
  - BDI/BDA
  - In-Line Technology
  - Supersonic Applications

MAFIS Proven Hard Target Fuze

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Safe Separation Study for MK 437 MOF*N* (Multi-Option Fuze *for Navy*)

50th NDIA Fuze Conference

May 9-11, 2006

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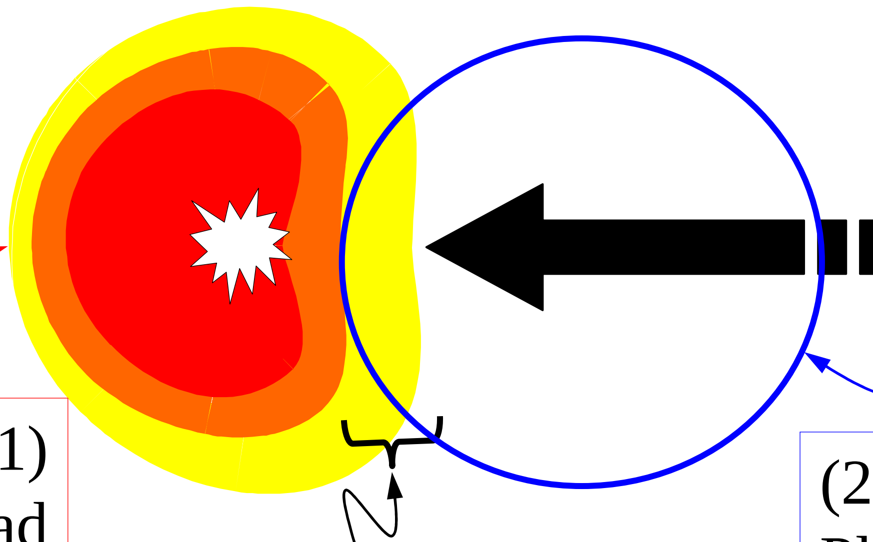
Introduction

- During the assessment of safe separation for MOFN there was much debate concerning methodology.
- This presentation is offered that other programs may benefit from the precedent set by MOFN which follows a safe separation assessment methodology of MIL-HDBK-504 *Guidance On Safety Criteria For Initiation Systems*.

Background on Safe Separation

- The need to perform a separation analysis is codified in MIL-STD-1316.
- Para 4.2.2, Requirement
  - *"A safety feature of the fuze shall provide an arming delay which assures that a safe separation distance can be achieved for all defined operational conditions."*
- Para 3.29, Definition
  - *"The minimum distance between the delivery system (or launcher) and the launched munition beyond which the hazards to the delivery system and its personnel resulting from the functioning of the munition are acceptable."*

General Methodology for Safe Separation Assessment



(4) Fly Out Conditions Modify Lethality Effects
- *Speed*
- *Direction*

(1) Warhead Lethality Effects
- *Fragmentation*
- *Over pressure*
- *Sound level*
- *Underwater Shock*

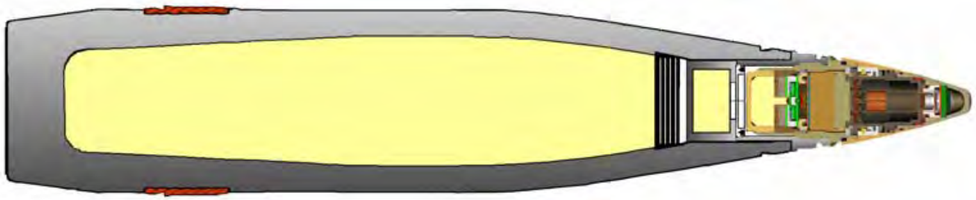
(3) Acceptable Hazard Level for Safe Separation
- *Safety Board Guidance*
- *MIL-HDBK-504*
- *MIL-STD-882*

(2) Platform Vulnerability
- *Material*
- *Personnel Protected*
- *Personnel*

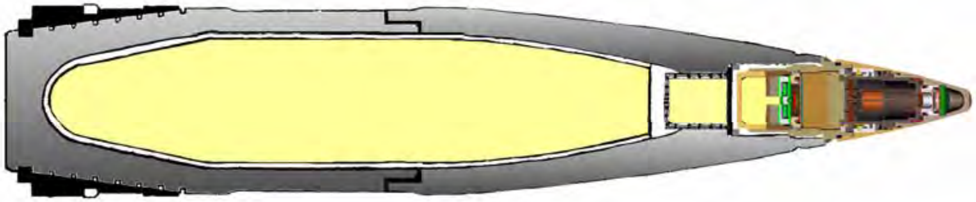
Analyzed at Worst Case Operational Condition

Warhead Lethality

MOFN has two potential warheads



EX 183 HE-MOFN
•MK 64 PROJECTILE BODY
•PBXN-106 EXPLOSIVE FILL



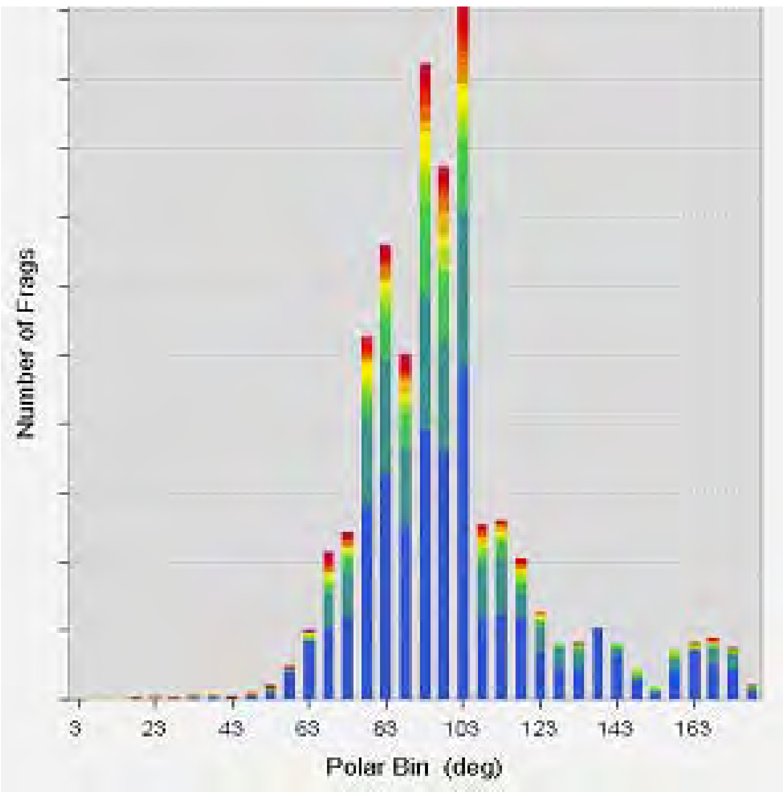
EX 184 HE-MOFN
•HIFRAG PROJECTILE BODY
•PBXN-106 EXPLOSIVE FILL

Warhead lethality effect is fragmentation

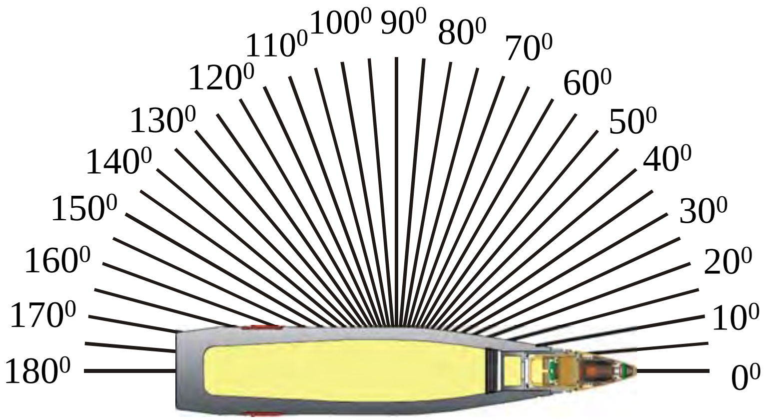
Warhead Lethality

- Warhead fragmentation characteristics determined with Arena Tests, min 3 tests of all-up munition (ref MIL-HDBK-504).
- Fragment size, location, and velocity captured.

Warhead Lethality



- Data is put into JMEMs[1] format:
- For each 5º spherical arc
  - Fragment size quantized into bins & averaged
  - Fragment velocity averaged



[1]JMEMs – Joint Munition Effectiveness Manuals

Platform Vulnerability

- Two ships carry the 5” gun: Destroyers and Cruisers.
- Cruiser was selected for study because it is a longer ship with a larger deck area.
- Cruisers have two 5” guns. The forward gun was selected for study because it has a greater range of motion.

DDG-51 Arleigh Burke class (Aegis) Destroyer

CG-47 Ticonderoga class Cruiser

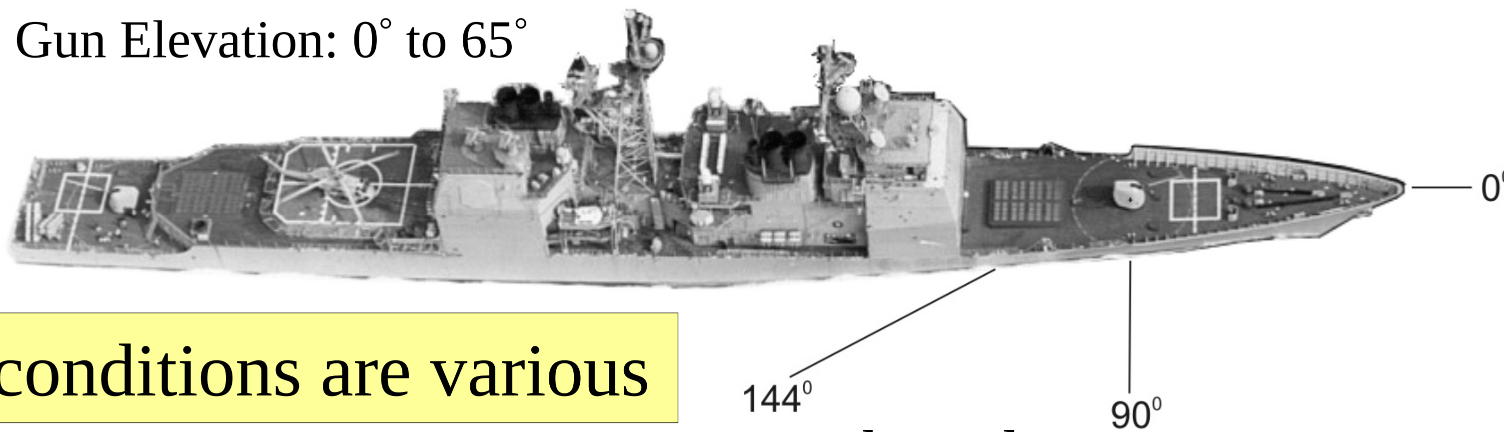
Platform Vulnerability

- Ship superstructure not as susceptible to damage as personnel who may be on deck.

Vulnerability based on personnel on deck using JMEM vulnerability models.

Fly Out Conditions

- Fly out defined by velocity and direction:
  - Velocity
    - MK 67 Mod 3 Standard Prop Charge: IV = 2650 fps
    - MK 68 Mod 2 Reduced Prop Charge: IV = 1500 fps
  - Direction
    - Gun Azimuth: 0° to 144°
    - Gun Elevation: 0° to 65°



Azimuth angles

Fly out conditions are various

Acceptable Hazard Level for Safe Separation

- MIL-HDBK-504, *Appendix A**, guidance:
  - Safe Separation Distance is the shortest distance where probability of a hazardous fragment hit from functioning of the munition is no greater than one in ten thousand (.0001)
  - A hazardous fragment is one with velocity greater than V_{50} for skin penetration.

Acceptable hazard level based on MIL-HDBK-504

**Note: Appendix B is for Air Launched Munitions*

Defined Operational Conditions

SAFE SEPARATION SCENARIOS										
Scenario #	1	2	3	4	5	6	7	8	9	10
Mission	AAW				NSFS		ASuW			
Elevation	+65°		+65°		+46°		0°		0°	
Azimuth	-144°		-144°		-90°		-144°		-144°	
Projectile	MK 64		HIFRAG		MK 64		MK 64		HIFRAG	
IV (ft/s) **	2,400	1,400	2,400	1,400	2,400	1,400	2,400	1,400	2,400	1,400

Ten scenarios correspond to 3 types of engagements:

- air targets (AAW),
- long range shore targets (NSFS), and
- close in surface targets (ASuW).

Worst case operational scenarios identified

***Note: IV includes 8% to 10% penalty as worst case*

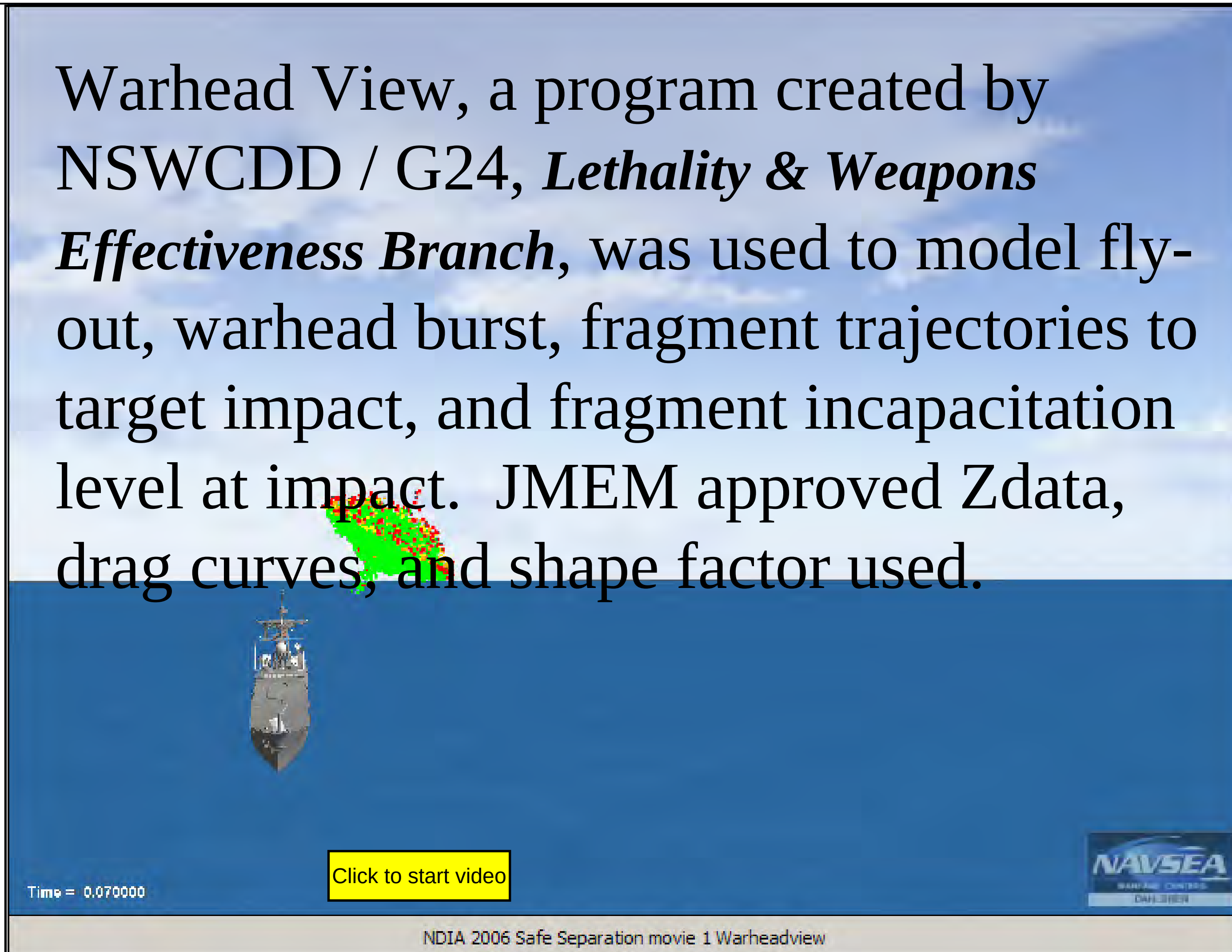
Safe Separation Distance

MK 64 proj.
150 ft range
Std Charge
90° Azimuth
60° Elev.

Frag Colors:

- 0 to 5 grams
- 5 to 10 grams
- 10 to 20 grams
- Above 20 grams

Warhead View, a program created by NSWCDD / G24, ***Lethality & Weapons Effectiveness Branch***, was used to model fly-out, warhead burst, fragment trajectories to target impact, and fragment incapacitation level at impact. JMEM approved Zdata, drag curves, and shape factor used.



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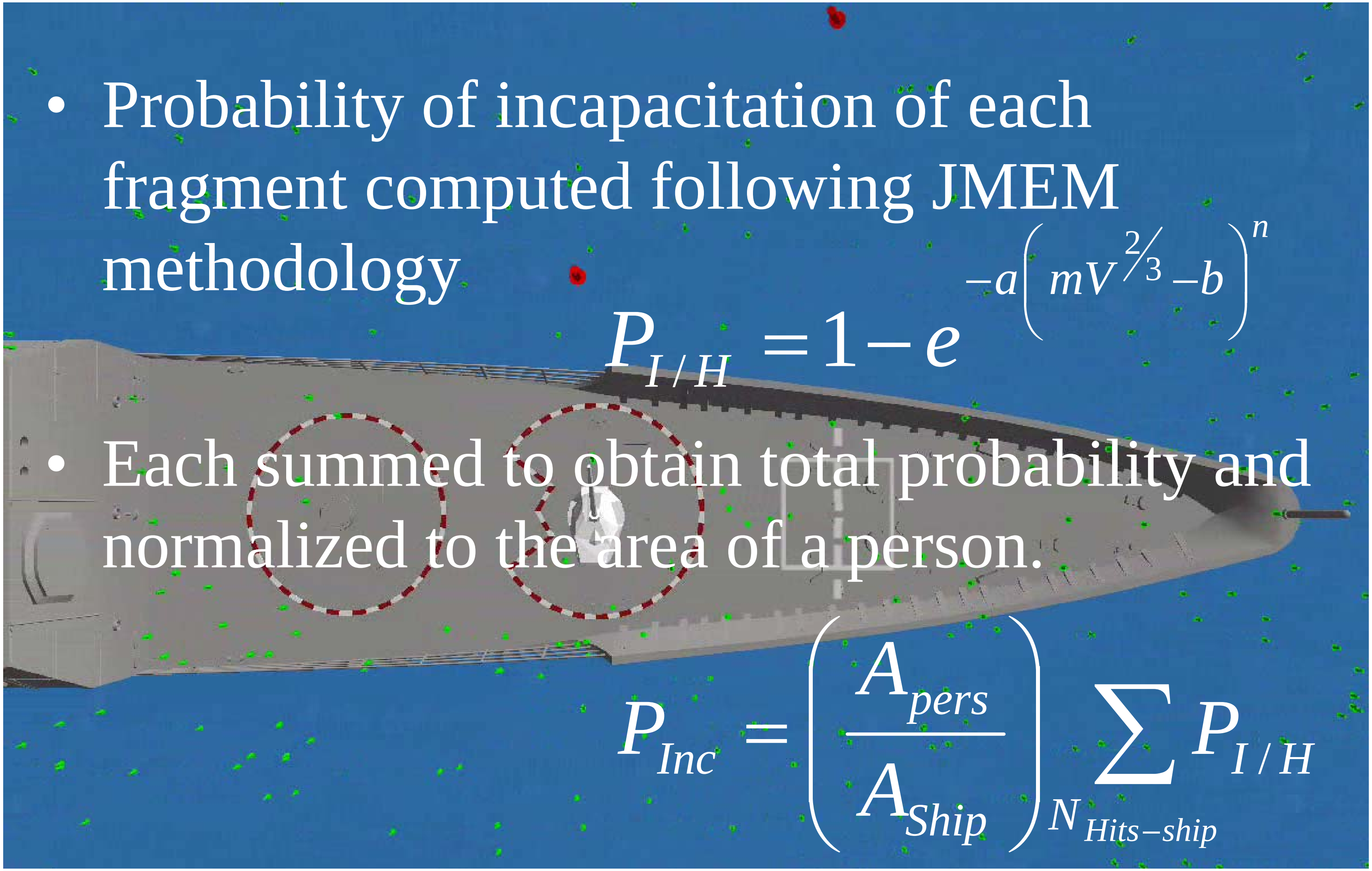
Safe Separation Distance



- Probability of incapacitation of each fragment computed following JMEM methodology

$$P_{I/H} = 1 - e^{-a\left(mV^{2/3} - b\right)^{n}}$$

- Each summed to obtain total probability and normalized to the area of a person.

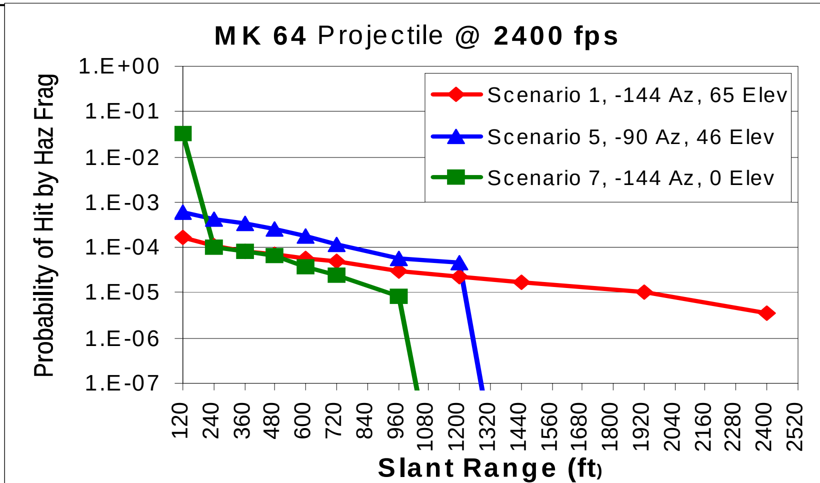
$$P_{Inc} = \left(\frac{A_{pers}}{A_{Ship}}\right) \sum_{N_{Hits-ship}} P_{I/H}$$

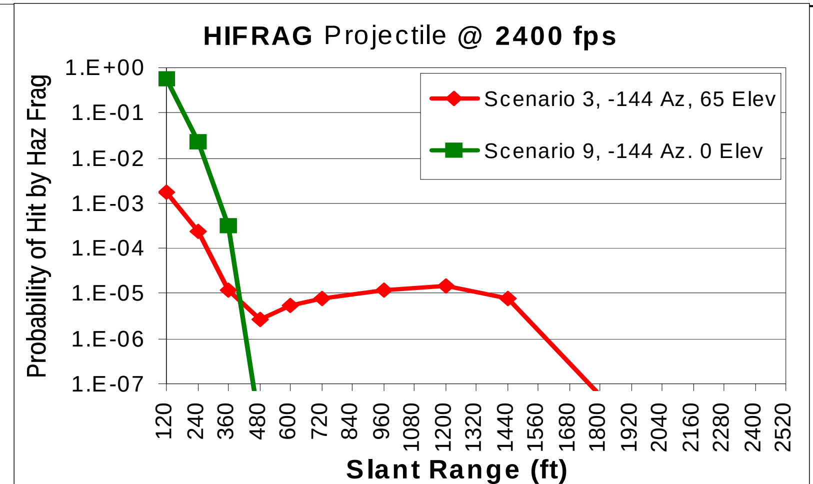
Safe Separation Distance

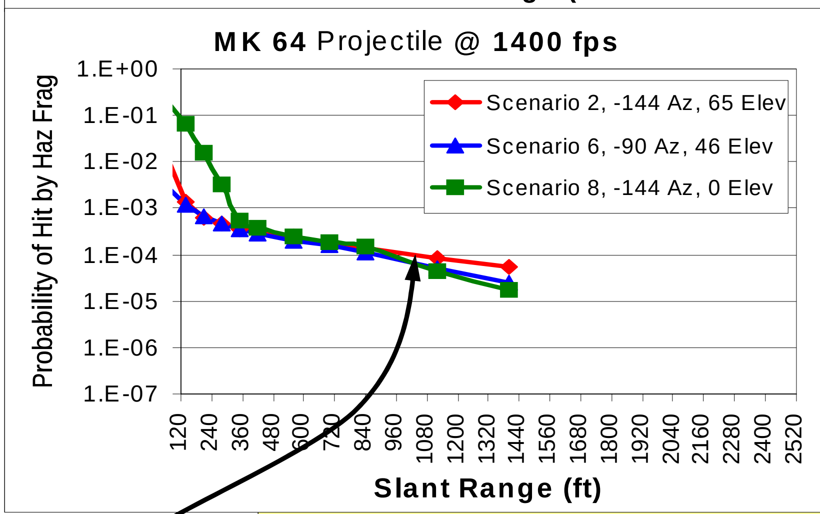
Sample data from Warhead View, 3 incapacitation levels computed

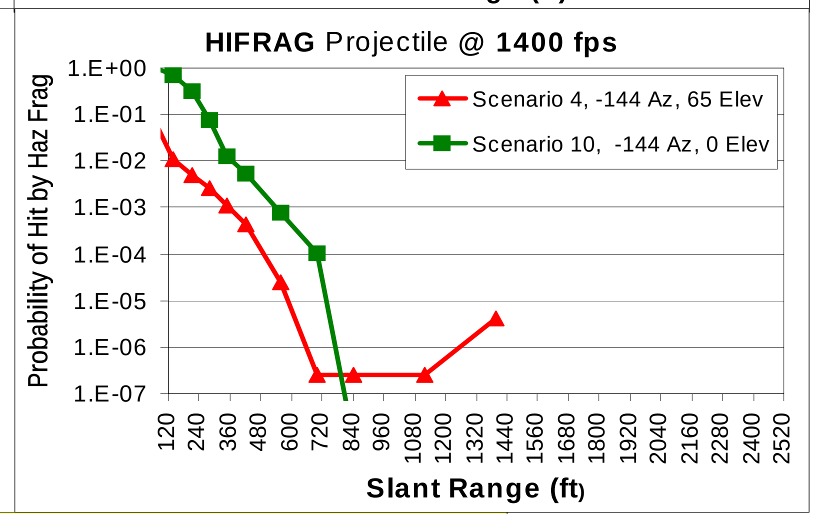
Scenario 1, -144° Azimuth, 65° Elevation				Probability of Incapacitation, 1 person		
Burst Time (s)	Slant Range (ft)	Average Number of Fragments Impacting ship	Average Fragment Mass (grains)	Lethal Wounding, Summer Clothing	Serious Wounding, Summer Clothing	Skin Penetration, Nude
0.05	120	398.1	10.78	0.0000710	0.0001648	0.0001705
0.10	240	446.9	8.73	0.0000413	0.0001060	0.0001105
0.15	360	494.7	8.04	0.0000280	0.0000800	0.0000843
0.20	480	459.5	8.95	0.0000205	0.0000648	0.0000693
0.25	600	330.4	12	0.0000153	0.0000520	0.0000568
0.30	720	216	17.8	0.0000120	0.0000443	0.0000490
0.40	960	79.9	43.06	0.0000063	0.0000255	0.0000290
0.50	1,200	35.2	83.67	0.0000045	0.0000195	0.0000225
0.60	1,440	17.1	134.37	0.0000033	0.0000148	0.0000170
0.80	1,920	4	387.64	0.0000020	0.0000085	0.0000100
1.00	2,400	1.7	634.26	0.0000008	0.0000030	0.0000035

Safe Separation Distance









Safe separation distance is 1010 ft

Operational Requirement for Close Engagement

- MOFN has a requirement for close-in engagement for ship self defense against small surface attack craft.
- MIL-HDBK-504 guidance is that a System Safety Risk Assessment (SSRA) be developed, per MIL-STD-882, and signed off by the Developer (PM) and User acknowledge and accepts the risk.
- 2 additional hazard assessments were performed.
  - Hazard of engaging target at min range.
  - Hazard of early burst at min arming.

Min Engagement Hazard

To determine hazard of Engaging Targets at Min Range:

1. Identify operational configuration.
2. Determine Incapacitation Probability due to warhead function.

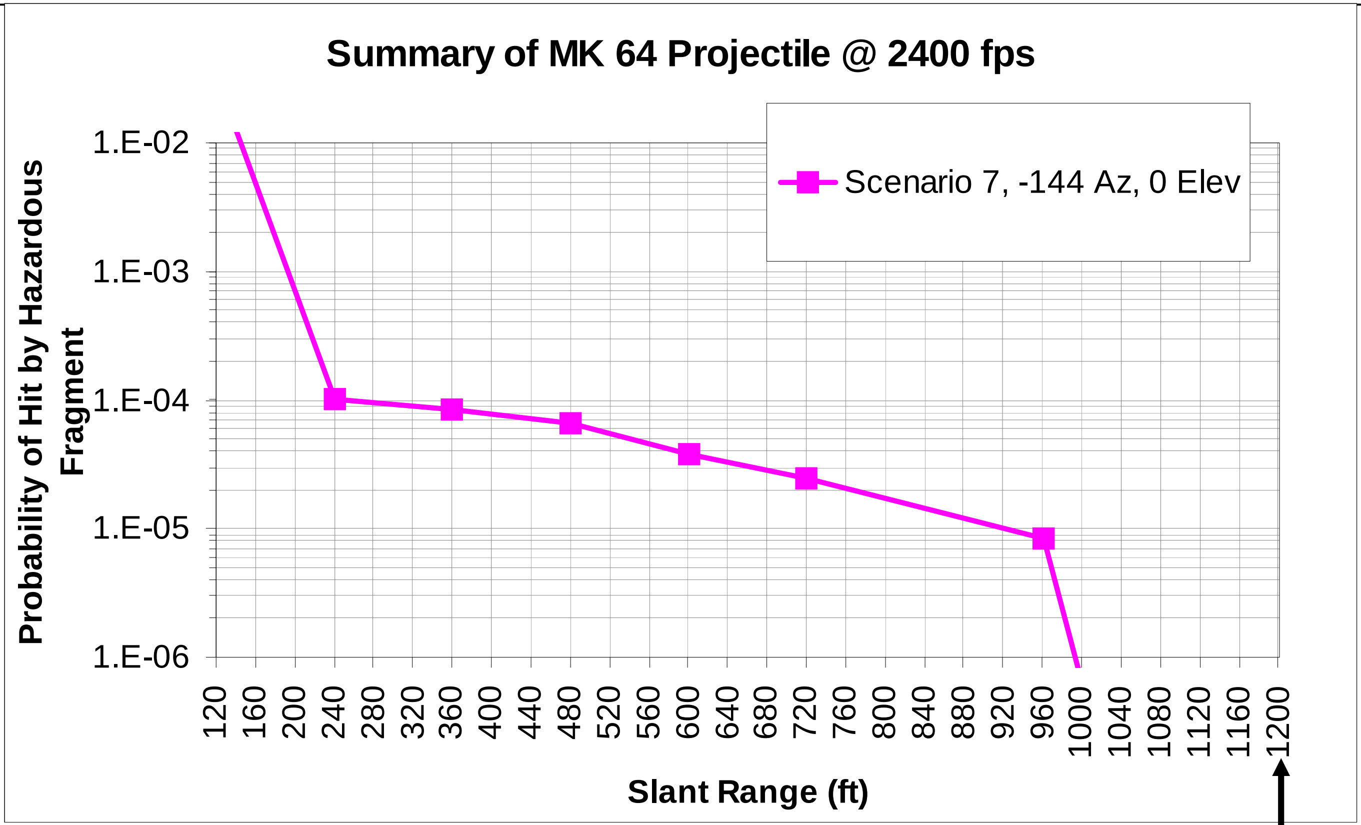
$$P_{inc/Det}$$

Min Engagement Hazard

- Worst Case Operational Configuration:
  - Projectile = EX 184 HE-MOFN
    - MK 64 Projectile w PBXN-106 fill

  - Propelling Charge = MK 67 Mod 3 Std Prop Charge
    - IV = 2650 fps
  - Platform = US Navy CG-47 Class Cruiser
    - Gun direction – 144 ° azimuth, 0° elev
  - Min Engagement Distance is 0.5s.
    - Firing Circuit disabled until 0.5s

Min Engagement Hazard



The hazard of engaging targets at minimum range is zero.

0.5s Minimum Engagement distance

Early Burst Hazard

- Early burst hazard at min arming presents a hazard that must be identified per MIL-STD-882 and accepted by the program.
- To determine hazard:
  1. Identify operational configuration.
  2. Determine probability of incapacitation from warhead function.
  3. Determine probability of warhead function.

$$P_{inc} = P_{Det} \times P_{inc/Det}$$

Incapacitation Probability

Warhead Function Probability

Early Burst Hazard

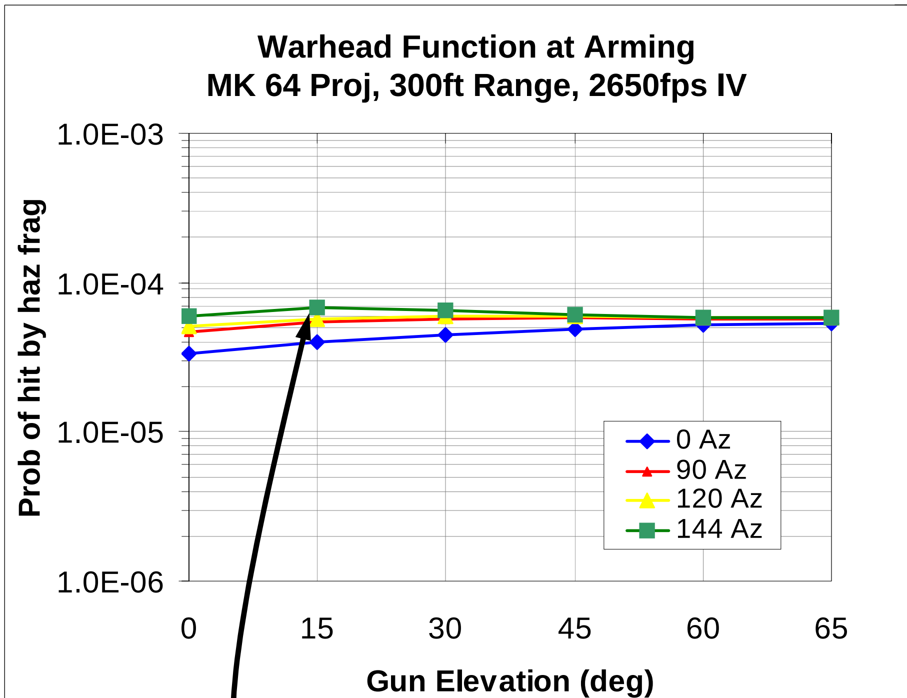
- Worst Case Operational Configuration:
  - Projectile = EX 184 HE-MOFN
    - MK 64 Projectile w PBXN-106 fill

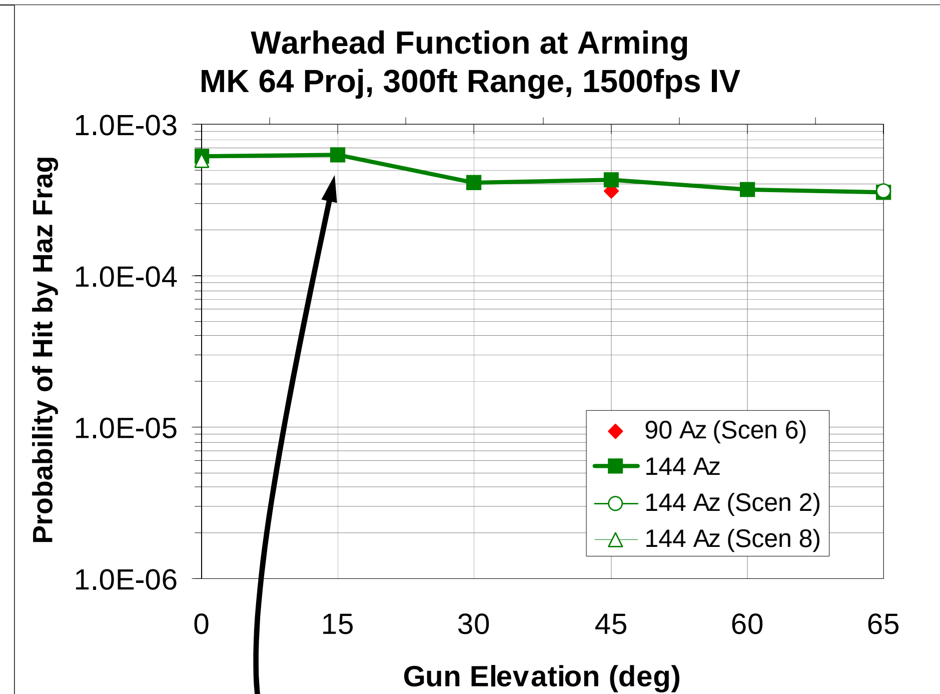
  - Propelling Charge = MK 68 Mod 2 Reduced Prop Charge
    - IV = 1500 fps
  - Platform = US Navy CG-47 Class Cruiser
    - Gun direction – survey of all

  - Average arming at 290 ft
    - Std Dev 7.1 ft

Incapacitation Probability

Probability of hit by hazardous fragment at arming distance





$$P_{inc/Det} = 5.0 \times 10^{-5}$$

At 2650 fps flyaway

$$P_{inc/Det} = 6.2 \times 10^{-4}$$

At 1500 fps flyaway

Warhead Function Probability

- Fuze is primary source of inadvertent warhead function.
- Quantity of test data is available from M782 MOFA production.
- Two failures (early bursts) out of 1,975 Lot Acceptance Test gun shots. Demonstrated failure rate of 1.0×10^{-3} *(note that that these failures caused rejection of the lot and are not representative of the stockpile)*.
- MOFA will be less than this because ………..

Warhead Function Probability

- Improvements to MOFN that will reduce safety failure rate.
  - Software rewritten following procedures for safety critical applications (IEEE/IEA 12207.1, 12207.2, and EIA/IEEE J-STD-016).
    - Over half a million software tests were performed with zero failures.
  - Cause of early bursts in MOFA tests has been identified and will be corrected in MOFN production. Army estimate of safety failure rate, between arming and safe separation distance, is $1x10^{-8}$.

Early Burst Hazard

- Early burst hazard at min arming distance is:

$$P_{inc} = P_{Det} \times P_{inc/Det}$$

$$P_{inc} = \left(2.6 \times 10^{-8}\right) \times \left(2.6 \times 10^{-4}\right)$$

$$P_{inc} = 2.6 \times 10^{-12}$$

- Probability of hit by a hazardous fragment is less than 1 in a million for the worst case condition.
- Severity of hit is skin penetration (50% probability) which corresponds to level III of MIL-STD-882 (injury resulting in one or more lost work days).

Early Burst Hazard

Hazard Risk Index of MIL-STD-882

Frequency of Occurrence (over the life of an item)	Severity of Occurrence: CATASTROPHIC (I)	CRITICAL (II)	MARGINAL (III)	NEGLIGIBLE (IV)
FREQUENT (A) $P > 10^{-1}$	I-A	II-A	III-A	IV-A
PROBABLE (B) $10^{-1} > P > 10^{-2}$	I-B	II-B	III-B	IV-B
OCCASIONAL (C) $10^{-2} > P > 10^{-3}$	I-C	II-C	III-C	IV-C
REMOTE (D) $10^{-3} > P > 10^{-6}$	I-D	II-D	III-D	IV-D
IMPROBABLE (E) $10^{-6} > P$	I-E	II-E	III-E	IV-E

Level of Risk Acceptance, Navy
High ASN-RDA
Serious PEO
Medium PM
Low PM

Hazard Risk Index per MIL-STD-882 is III-E.
This hazard must be formally accepted by the Program Manager.

USS Lassen Malfunction Investigation

Real Life Example of why we do safe separation studies

- 2 Feb 2005, USS Lassen DDG-82, had a close aboard detonation at a reported distance of 150 feet.
- Weapon was a D350 5” High Explosive projectile:
  - M732 Fuze, MK 64 body, Comp A-3 fill
  - Standard Propelling charge
- The gun barrel was pointing 82° azimuth to port side, and 7.1° elevation.

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USS Lassen Malfunction Investigation

- Model of USS Lassen incident

Color Code

Fragment size

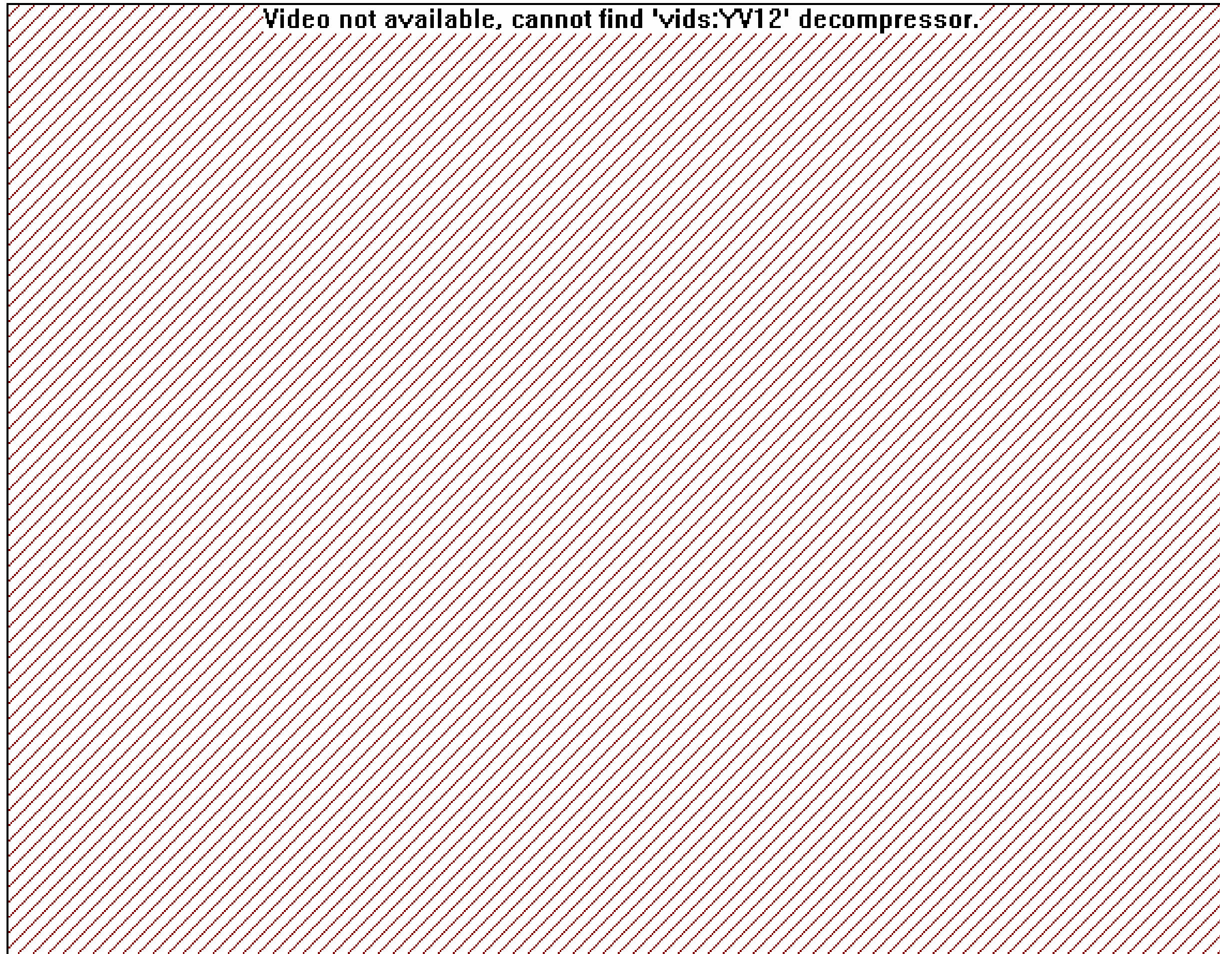
1000 grains

100 grains

30 grains (22 bullet)

10 grains (BB)

1 grain



NDIA 2006 Safe Separation movie 2 USS Lassen

USS Lassen Malfunction Investigation

- No injuries resulted from incident.
- Very little data was available for the incident; no IV, video, or audio to confirm estimated distance of detonation. Crew reported 2 “small” fragments on deck. Fragments were discarded.

The “small” fragments found on deck are not inconsistent with predictions.

USS Lassen Malfunction Investigation

- *Malfunction was probably fuze function at arming due to a design weakness particular to the M732 fuze.*
- *Two independent assembly errors, occurring in the same fuze, will allow the fuze to detonate on arming. (Note that the M732A1 corrected this problem)*
- *Arming distance in 5" gun is about 295 ft.*

USS Lassen Malfunction Investigation

- *Historical research:*
  - *2.4 million fuzes were fired by Army, USMC, & Navy*
  - *4 incidents of detonation at arming reported by Army, 5 including Navy*
  - *No correlation to manufacturer or to lot number*
  - *No material or personnel injury*
- *Conclusion: Because screening is impractical, and probability of event is so low and probability of injury is so low, investigation was closed with only an advisory to ship captains.*

Summary / Conclusions

- Determination of safe separation distance takes 4 factors, analyzed at worst case operational condition:
  1. Warhead lethality effects
  2. Platform vulnerability
  3. Fly-out conditions which may modify warhead lethality effects
  4. Acceptable hazard for safe separation
- If there is a requirement to engage targets within safe separation distance, a System Safety Risk Assessment (SSRA) is to be developed and signed off by the Developer (PM) and User acknowledge and accepts the risk.